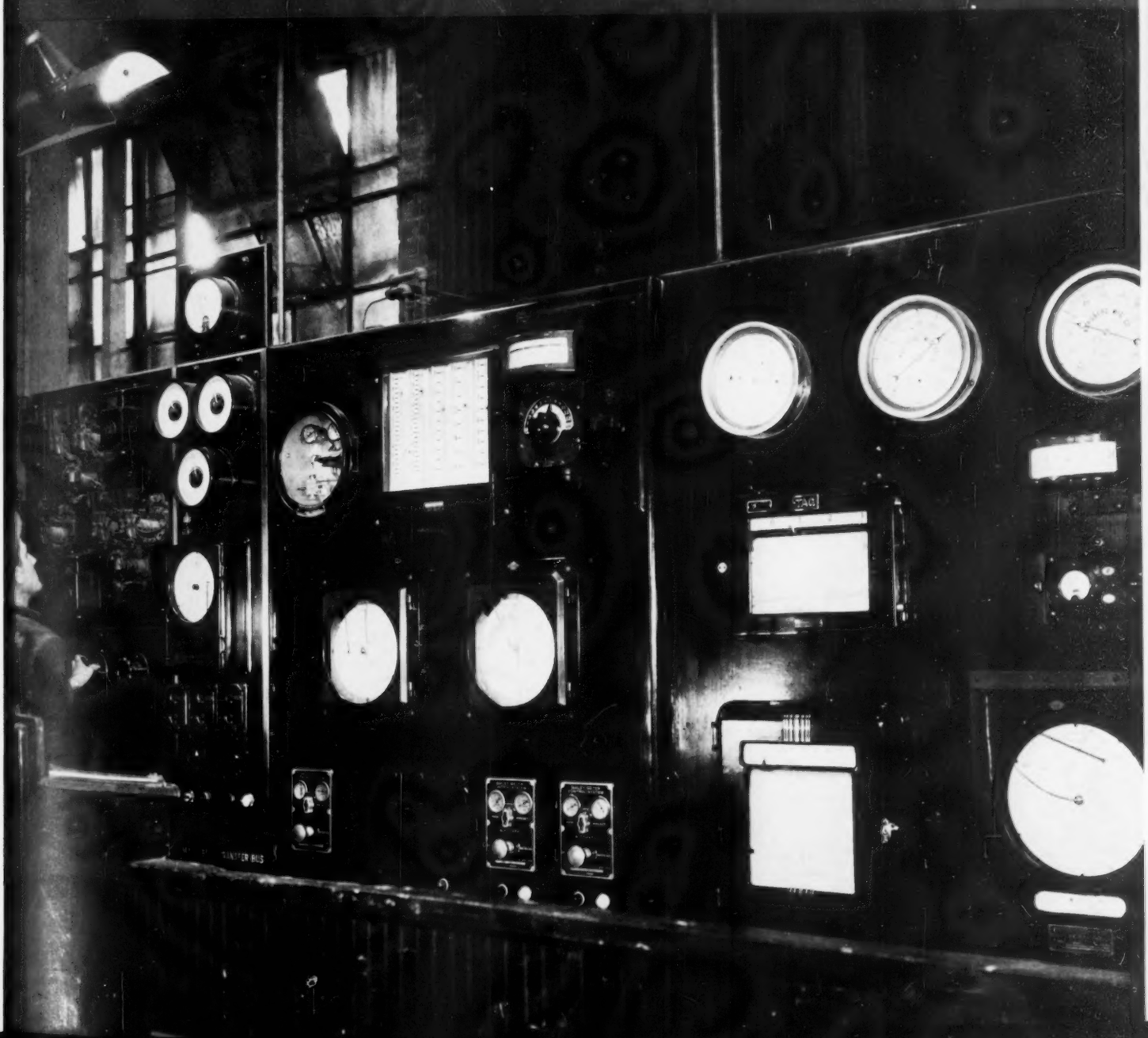
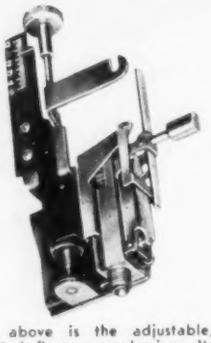
Instruments

THE MAGAZINE OF Measurement and Control

Vol. 12
MAY
1939
No. 5



Guarding Product Quality with Precise Indicating Control



Shown above is the adjustable, calibrated flapper mechanism. Its design permits easy adjustment of throttling range to coincide with great apparatus lag.

Shown above is the redesigned, non-adjustable flapper mechanism in its simplest form . . . the ideal pilot for a great majority of control applications.

A COMPLETE LINE OF TAG INDICATING CONTROLLERS . . . "ON-OFF" AND THROTTLING MODELS

In guarding quality and maintaining product uniformity by dependable supervision of temperatures, TAG Control has become a by-word in process operation. The Indicating Controller was designed not only for real operating convenience, but also to cope with stiff plant conditions. So now the entire line of TAG Indicating Controllers is presented in moisture-proof, aluminum cases—beautifully finished in black enamel with chromium trim.

All the latest TAG developments plus the sound principles and approved standards long present in TAG Air-operated Control are to be found in these reliable instruments. There's a new Bulletin No. 1175-I which describes both the "ON-OFF" and Throttling Models . . . it will tell you what you want to know about them.

C. J. TAGLIABUE MFG. CO.

Park & Nostrand Ave's., Brooklyn, N. Y.

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IN A

RECORDING CONTROLLING PYROMETER

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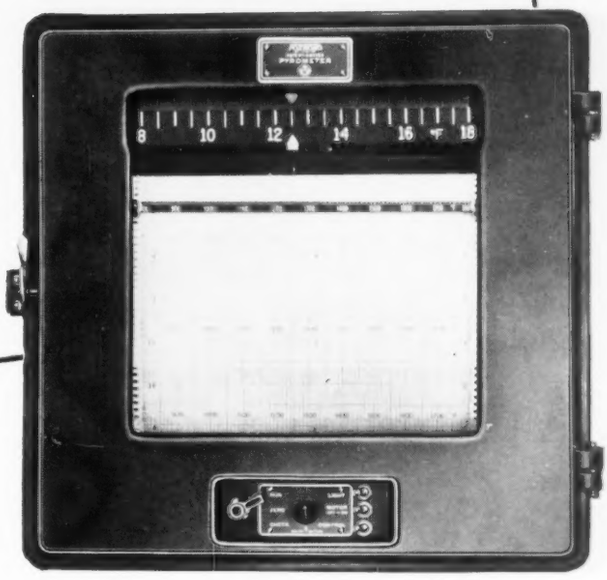
2. Precise Transference of Measurement to Chart Record and Control Mechanism
3. Accurate, Dependable Control with Positive Contacts
4. Flexibility to Provide Combination of Control Circuits
5. Long, Maintenance-free Life



Recently perfected and offered to industry, this modern control instrument has met with instant approval by users who know Pyrometers. Two proved Foxboro systems have been engineered into a perfect combination, so that the slightest change in measurement produces a corresponding movement of record and control system. There are no links, belts, or gears in the detecting-recording-controlling mechanism to cause inaccuracies. Precise and dependable operation is a lasting quality of the Foxboro Recording Controlling Pyrometer. » » » You will be interested in the contact construction which makes possible the operation of control and signals, or different phases of regulation through separate circuits in one instrument. Bulletin 765 gives the whole story of this modern instrument. Write for a copy.

THE FOXBORO COMPANY
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Instruments
THE MAGAZINE OF MEASUREMENT and CONTROL

Vol. 12 No. 5

MAY 1939

FRONT COVER: Instrument board on No. 2 Electric Furnace and Acid Plant, TVA Fertilizer Works, Wilson Dam, Ala.

(The article on this plant's instrumentation will appear in our next issue.)

EDITORIAL COMMENT 127

NEW INSTRUMENTS 128
Indicators, recorders, controllers, inspection devices, etc., for plant, field and laboratory

INSTRUMENT ANALYSIS 137
General Principles
By C. S. Draper and G. V. Schliestett

INTEGRATING RING AREAS 143
A New Method
By E. R. Schafer and J. C. Pew

TILLAGE TOOL RESEARCH 144
Projected model experiment station
By K. J. DeJuhasz and A. W. Clyde

MANUFACTURERS' NEW LITERATURE (Insert)

ADVERTISERS' INDEX ..... (Insert)

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Instruments

THE MAGAZINE OF *Measurement and Control*

M. F. BEHAR, Editor

World of To-morrow

YOU who read *Instruments* have not given up hope for a better to-morrow, in spite of the anti-machine propaganda. No! The very fact that you use *Instruments* as a data source to improve your plant and laboratory equipments and methods—this very fact proves that you not only hope but have rolled up your sleeves to help create a better to-morrow.

We who serve you are equally hopeful.

But a wish-bone isn't much good without a back-bone. We believe that a good way of rolling up our sleeves in your service is to hew to the line every month on this page. We believe that it would be cowardly, in these times, to let this page become a banal, neutral, vapid Mister Milquetoast, and shall keep on hitting enemies of technological progress!

We became more hopeful a few days ago, when we managed to squeeze in a visit to the Fair between week-end engagements in New York: Soon, millions will view the inspiring exhibits; many will rid themselves of hate-germs; will realize that the better to-morrow is being built by to-day's Invention and Research—especially Research, as is impressively brought out in breath-taking exhibits.

But what a shock it was to find, on returning to our desk:

Machines Over Men. By RAYMOND F. YATES. Frederick A. Stokes Co., New York, 1939. Gold-embossed cloth, 5½ × 8½ inches, xx + 250 pages, 25 plates. Price $2.50.

This is a popular-format book, with an attractive jacket, inviting blurbs and artifices designed to make a best-seller. It might become a best-seller, for the publishers plug it as

A clear and splendidly illustrated story of the scientific advance of the amazing machines that surround us and shape our lives today. . . . so that unscientific men and women may see and understand as never before this complex age we live in.

In our opinion it is a muddy and stupidly-illustrated tract, whose unscientific readers will be plunged in darker ignorance and prejudices. The publishers go on to say that

On the well-founded principle that to cope with one's enemy it is first of all imperative to understand him, Raymond Yates here gives us a comprehensive analysis of what the modern robot is . . .

and here they let the cat out of the bag, by calling the machine "enemy." They assert that the author's aim

. . . is not to weigh the social problem of the presence of the machine, but simply to draw his [*sic*] portrait and show him in action . . .

and Yates closes his Introduction by asserting:

It is my purpose here rather to view the machine in itself, minus its still little-understood social implications. [Page xix]

but the falsity of these two assertions is made evident by discussions of social implications in the Introduction itself and in at least ten passages throughout the book. Examples:

The apologists for the machine age doggedly maintain that machines have increased employment by reducing prices and raising consumption. . . . Practical people . . . see an ever-widening breach between the theory that the machine increases employment and the fact that unemployment is relentlessly increasing. [Page xviii]

The workers who have been able to escape the consequences of such encroachment [labor-saving machines] have in many instances been assigned to supervisory functioning; mere feeders and operators of switches, levers and buttons. . . . Now even the machine controller, supervisor or feeder stands in jeopardy of losing his job to a litter of glass tubes. The threat is real enough. No one can gainsay that and, although we promised at the outset to refrain from permitting our discussion to ooze over into the social problem, we cannot help but wonder who eventually will be left with money to buy our machine-made ice-boxes, radios and automobiles. [Pages 64-65]

Oftentimes robots peek out at us from unexpected nooks. The automatic telephone is one of the most fearful of the species. Eventually it will release to the streets several hundred thousand telephone operators, thus helping us to plan our next depression. [Page 79. Reviewer's note: Every advance in A.T.&T. automatization has *increased* the company's payroll.]

The alarming growth of arthritis, rheumatism and neuritis . . . is part of the price we are paying for our robots. [Page 131]

The Rust brothers' cotton picker. . . . Two modest, socialistic young men [*sic*] . . . This robot is no amateur. Within the short space of seven and one-half hours, it can do work that would take a man eleven weeks to accomplish. . . . Here is a body blow to that part of the nation least prepared to take it, the land of the share-cropper. Two million people already reduced to peonage stand trembling in fear of this new monster. [Pages 178-179]

. . . Increase in both juvenile and adult delinquency . . . It is barely possible that . . . the robot stands preeminent. He is undoubtedly one of the scoundrels . . . Has he not thrown millions of men into the streets seeking employment? Is it so daring to think that some of these, rather than starve or be humiliated by relief, prefer to exercise that latent talent toward a less arduous and more luxurious existence? . . . Perhaps most of our criminals have embraced the extra-legal method only out of pure desperation. [Pages 184-185]

It is beginning to appear that our bill for the robot is running high in human suffering, social and economic maladjustment. We may have to pay that bill some day and what an accounting it will be! [Page 233]

Strong stuff, eh? But what kind of an American is Yates? Is he red, middle-of-the-road, or reactionary? You can form your own conclusion from these excerpts:

A bare total of 400,000 inventions had been patented by the year 1890. Now over 60,000 issue yearly, and that could easily be doubled if wilful sabotage were not a factor and a creaky economic system were able to bear up under the burden of more research and had greater capacity to assimilate the products of genius. [Page xv]

Henry Ford . . . has a bullet-proof idea for a still-more robotized farm. When Henry speaks, the pencils of the newspapermen snake across their scribbling paper with gusto. Any one who places $5,000,000 worth of newspaper advertising each year could get the same attention; but that would be no index of his sanity. Ford's enthusiasm is always outstripping his intelligence. Now he wants to make every farmer a fond mother for acres of soya beans that will be used to make plastics for automobiles. . . . Just how these growers of soya beans might fare during a depression or while Ford was changing over from a Model-T to a Model-A, is not mentioned. [Pages 176-177]

Apart from holding these views, does Yates know what he is writing about? The reviewer has written technical books, has learned that it is humanly impossible to avoid slips, has grown lenient towards his confrères, but has to report finding about thirty gross errors. Examples:

"Crystallization" of springs. [Page 26]

"Unattached electrons may be gathered and forced through metallic wires. They then manifest themselves as an electric current, their number determining the amperage or working capacity of the current, and their speed its voltage." Further, "electron-controlled contactor" to designate a power tube which obviates the need of contacts. Pages 44-50 will edify electrical engineers!

Full-page plate facing page 74 bears caption: "If you were to take the cork from a bottle of mercury and hold the mouth of the bottle under the 'nose' of this robot, he would siren out a warning . . ." but the photograph shows the G-E's *non*-signaling, *non*-automatic mercury vapor detector, which simply utilizes the darkening of selenium monosulphide paper; whereas the caption was apparently adapted from an item on G-E's automatic detector which utilizes the resonant radiation method. (See *Instruments*, Nov. 1933, page 211; March 1936, page 61; Feb. 1939, page 62; and you will agree that this is not a mere slip but woeful ignorance.)

"In the field of war the robot still has to make his mark." [Page 89] Descriptions of non-secret military and naval applications could fill a book twice as long as "Machines Over Men."

Pages 135 to 138 on ectogenesis, genes, etc., will edify biologists—especially the triumphant conclusion: "Perhaps the cosmic rays are exerting a profound influence . . . difference between a thief and an honest banker . . . it may be that astrology rests on a rather firm foundation."

Sixteen-page Chapter VI, "The Robot Goes to Court," will edify serious criminologists who know the limitations of so-called "lie detectors." Yates apparently swallows all the yellow-newspaper

(Continued on page 145)

THE MONTH'S NEW INSTRUMENTS

In this department we strive to report each month ALL the new devices for measurement, inspection, testing, metering and automatic control—in the form of concise technical descriptions.

When writing to manufacturers directly, please mention this department as your source of information.

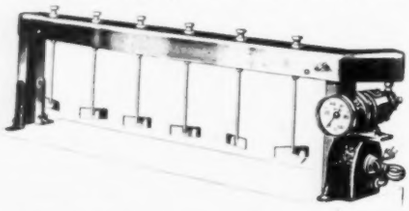
Or write to Information Section, Instruments Publishing Company.

Specimen Dryer

Designed for drying polished metallographic specimens in 30 seconds, new No. 5100 Dryer employs a current of heated air which, by virtue of the contour of the depressable grate holder, is directed against sides, top and bottom of specimen. After drying, specimen is cooled in place by turning switch to "No. 1" position. Motor is a specially-selected model with large sleeve bearings and wick-fed light-grease lubrication; heating element consists of special-alloy windings on mica frame. —*Harry W. Dietert Co., 9330 Roselawn Ave., Detroit, Mich.*

Multiple-unit Mixers

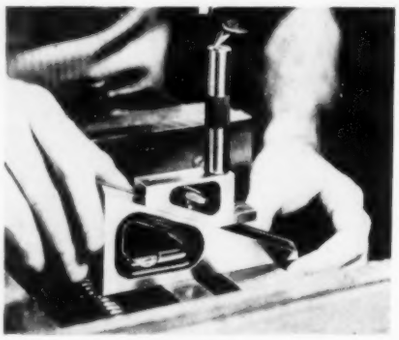
Two models of new Laboratory Mixer are announced: 4-unit and 6-unit, both designed to save time, chemicals and coagulants and properly dose wash water. Con-



tinuously-variable speeds from 10 to 100 r.p.m. (up to 200 r.p.m. on special order) are controlled by heavy-duty rheostat. All tachometers are individually calibrated.—*Phipps & Bird, Inc., Richmond, Va.*

Planer and Shaper Gage

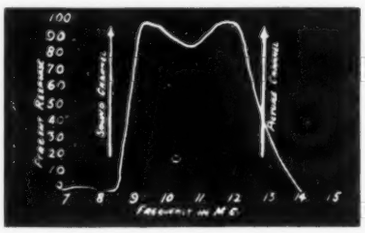
In new Model 599 Planer and Shaper Gage, alignment and parallellism of ends, sides and work contacts are held to much closer limits and lateral play of slide and

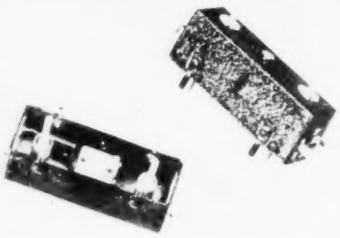


base is eliminated through the use of angular ways. Its range, with the 3" extension used on longer measurements, is ¼" to 9". Level built into base of gage is useful when setting up work on planer table. Base and slide are hardened steel forgings with all working surfaces ground. Base dimensions ⅜" wide, 5¼" long. Extension is ⅝" diam., 3" long. Total weight approx. 25 oz.—*L. S. Starrett Co., Athol, Mass.*

I-f. Transformers

New i-f. transformers designed especially for television sound and picture channels are of perm-trimmed type, said to permit maximum gain per unit with desired band

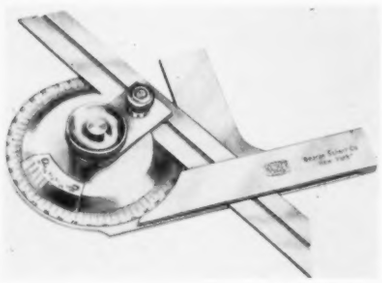




width for high-definition television. They include trap circuits required to eliminate, from picture channel, interference caused by its sound carrier and by adjacent channel sound carrier. Units measure 3¼" long by 1" wide and 1-5/32" high. Terminals extend from both ends of shield. *The F. W. Sickles Company, Springfield, Mass.*

Universal Bevel Protractor

New Mauser Universal Bevel Protractor may be used for all types of work where angles must be laid out or measured. Dial is graduated in degrees: 0-90 in each quad-



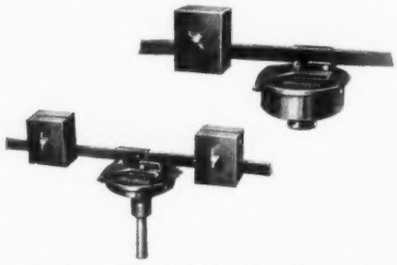
rant for full circle, with vernier reading within 5' of arc. Protractor may be obtained with 6", 8" or 12" blades, bevelled at each end to 45° and 60° respectively. Its back is finished flat for flush laying on work or paper. Blade may be clamped independently of dial.—*George Scherr Co., 128 Lafayette St., New York City.*

Time Switch

Designed primarily to control operation of electrical equipment with non-inductive load of 10 amps. at 110 v., 5 amps. at 220 v. or motors of 1 h.p.r.i., ½ h.p.s.p. or ¼ h.p.d.c., either 110-v. or 220-v. rating. Type S403A Timer may be manually set to close the circuit and will automatically break the circuit at a predetermined time for any period from ½ hour to 11 hours. It is put into operation by setting the knob until desired time interval appears on dial. Twisting the knob in counterclockwise direction will turn current off. Timing mechanism cannot be overwound so that it sticks. "Con-Tac-Tor" mercury switch is of such design that leveling by sight is sufficient in making installation.—*Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.*

Boiler Regulators

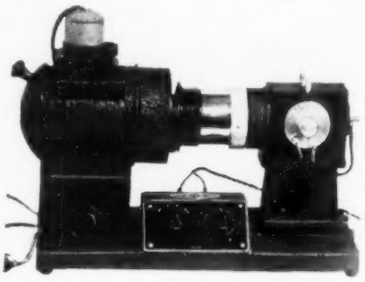
(1) New "Type M512A Metaphram Steam Boiler Regulator" operates boiler draft and check dampers by an external lever, in accordance with pressure within its "Metaphrams." It is for application to small steam boilers requiring no more than 3" total movement of dampers. Available in four sizes.



(2) New "Type M513A Hot Water Boiler Regulator" is self-contained, operates boiler draft and check dampers by an external lever in accordance with temperature of water surrounding its primary element. It has 1" pipe thread connection.—*Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.*

Fluorophotometer

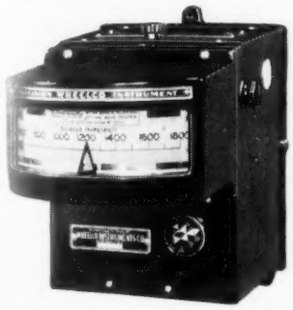
New Model A Fluorophotometer has been designed primarily for measuring degree of fluorescence of liquids and solutions. Its construction permits also fluorescent an-



alysis and it may be used for absorption and comparison measurements similar to those of standard colorimetry and turbidimetry.—*Pfaltz & Bauer, Inc., Empire State Bldg., New York City.*

NOW

Wheelco Series 3200



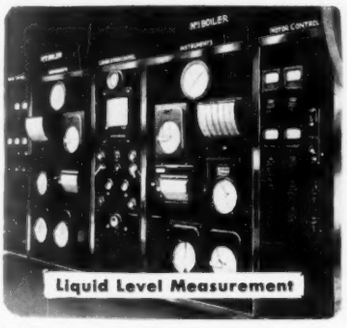
POTENTIOMETER CONTROLLER

Matching the unusual sensitivity of the Famous CAPACITROL control system with the well established accuracy of the potentiometric method of temperature measurement, Wheelco again leads in supreme performance by offering this unbelievable solution for control problems of extreme accuracy and sensitivity.

Write for Bulletin 3200

Wheelco Instruments Co.
1933 So. Halsted St. Chicago, Ill.

Increase Boiler Efficiency with COCHRANE Flow Meters



THE above panel is one of the many Cochrane installations that are daily saving power plants thousands of dollars through increased efficiency by the accurate recording of boiler conditions. It serves two 120,000 lbs. per hour boiler units and includes Cochrane Flow Meters for measuring boiler feed water input, and Cochrane Liquid Level Meters for providing continuous records of boiler drum levels.

Cochrane Flow Meters are made in both electrical and mechanical types to fulfill individual power plant needs. They are preferred by leading industrialists because of their extreme accuracy.

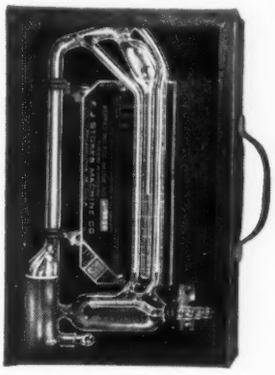
Write for Bulletin Nos. 2096 and 2094.

COCHRANE CORPORATION
3120 N. 17th St., Philadelphia, Pa.

COCHRANE
FLOW METERS

Portable Vacuum Gage

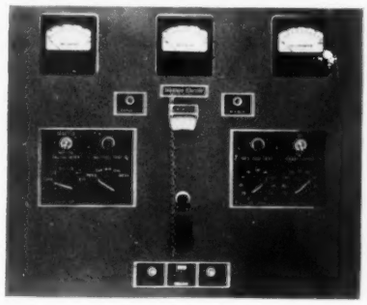
New McLeod type vacuum gage can be carried about without danger of breakage or spilling mercury, in whatever position it may be held or however rapidly that position may be changed. Single readings take 2 to 5 seconds, can be made in rapid succession (6 per minute) by turning gage from horizontal (evacuated) position to vertical (reading) position. Readings are made, in microns, from the center capillary.



Mercury comes up automatically to proper level in right capillary tube. Gage weighs 4½ lbs. with mercury, measures 7" × 11" × 2", covers range from 0 to 5000 microns (5 mm.), is provided with a swivel bracket for mounting in permanent position. Stops are provided and swivel is so balanced that gage returns to horizontal or evacuated position when released.—*F. J. Stokes Machine Co., Olney P. O., Philadelphia, Pa.*

R-f. Phase Monitor

For controlling the area within which a broadcasting station is heard, new Phase Monitor "2A" indicates both phase and magnitude of r-f. current in each antenna



tower. It is said that performance of computed field patterns, "which heretofore could be determined only by elaborate field-strength surveys requiring a portable laboratory and days of painstaking effort to complete, may be closely ascertained with the new instrument in a matter of minutes." Samples of antenna current, procured from a small loop associated with each radiating structure, are led by coaxial transmission lines to the instrument's permanent location within station. Here, engineer observes relative current strength between towers on a pair of direct-reading indicators. A quickly-operating control permits operator to interchange both indicators and their associated circuits, thus providing a check. Phase angle is ascertained by rotating a single graduated dial until magnitude and phase of one sample exactly opposes that of a second sample, as indicated by a special galvanometer. Phase Monitor weighs 43 lbs., measures 15¾" × 7½", employs four vacuum tubes, all operated 25% below normal ratings.—*Western Electric Co., 195 Broadway, New York City.*

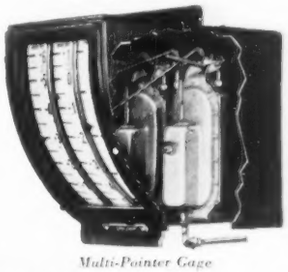
BAILEY METERS

METERS and CONTROL *for Boiler Room Service . . .*

Boiler Meters Indicate, record and integrate Steam Flow from the boiler, record Air Flow supplied for combustion and record Flue Gas Temperature. The use of this meter reduces fuel cost, lessens maintenance and outage, lowers standby costs, and adds capacity.

Bailey Boiler Meter

Multi-Pointer Gages for indicating drafts, pressures, differentials are available with any number of pointers from one to twelve. They are actuated by sturdy yet sensitive diaphragm units.



Multi-Pointer Gage

Flow Meters. For indicating, recording and integrating the flow of steam, feed water, compressed air and other fluids.

Coal Meter

Granular Material Meters For accurately measuring the flow of coal or other granular materials in gravity chutes from overhead bunkers. The total quantity of granular material is shown on a large illuminated counter which may be easily read at a distance of 50 feet.

Control Systems. Make possible the everyday operation of equipment for steam generation and utilization at test efficiencies. They are applied to the control of combustion, feed water, superheat, desuperheat and other factors.

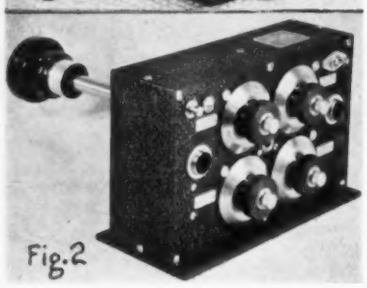
Complete Information on any of the above Bailey products will be gladly furnished upon request.

G-7

BAILEY METER COMPANY
1041 Ivanhoe Rd., Cleveland, Ohio

Multi-circuit Contactor for Engine-indicator Systems

Designed for use with pressure pickups and with RCA Type 164 amplifier and Type 304-A 9" cathode-ray oscillograph in high-speed engine testing equipments, new "Piezo



Ray" Multi-circuit Contactor holds image in fixed position on oscillograph screen regardless of changes in engine speed. It is available in four types, each of which, in addition to thus "locking the card" in constant relation to rotating member, permits selection of two card lengths. Simplest of the four is Type I (Fig. 1) for crank-shaft speed and for 180° or 360° card length. Type II is for half crank shaft speed and for 180°-360° or 180°-720° or 360°-720°. Type III provides additionally a dead-center marker and an angle finder. Type IV (Fig. 2) has all the foregoing features and also a camera timer or rotary switch. Drive shafts, flexible couplings and other auxiliaries, developed for eliminating common sources of error, are available.—*Commercial Engineering Labs., 5612 Woodward Ave., Detroit, Mich.*

Differential Controllers

New "Differential Pressuretrol" and "Differential Thermostat" both employ same principle: bellows assemblies that oppose each other and respond to differential pres-

sures or in temperatures. Differential Pressuretrol, when connected to an orifice, can be used to control flow of steam or liquids, to sound an alarm, etc. Differential Thermostats can be used for water conservation on air conditioning jobs using well water; on attic fans (one element in outside air and one in the house); to prevent condensation in underground wiring tunnels by keeping temperature above that of outside air, etc. Both instruments are available in throttling as well as in mercury-switch models.—*Minneapolis-Honeywell Regulator Co., 2950 Fourth Avenue South, Minneapolis, Minn.*

Wheelco "Radio Principle"
INDICATING CONTROL THERMOMETER

The combination of the famous Wheelco "Radio Principle" CAPACITROL controller and a bourdon tube assembly produces temperature indicating accuracy and control sensitivity unequalled by any other known method. A radio impulse does the work. There are no contacts or moving mechanical parts to interfere with the performance of this instrument.

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Wheelco Instruments Co.
1933 So. Halsted St. Chicago, Ill.

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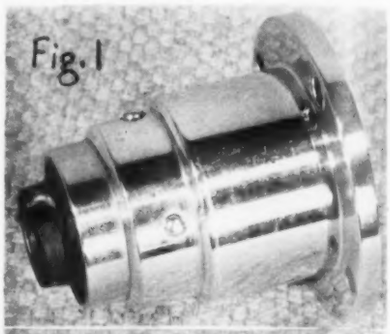
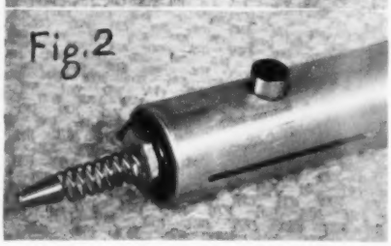
Torsional Vibration Pickup for Oscillograph Equipments

Newly added to "Piezo Ray" line of equipment is a Torsional Vibration Pickup which is not a piezoelectric but an electromagnetic unit. Fig. 1 shows this new pickup





with standard adapter flange for mounting on end of crankshafts or other rotating units. Generator case contains a permanent bar magnet which is free to rotate, and two field coils wound on a soft-iron core and rigidly fixed within case. In operation, case and coils rotate with shaft being studied; bar magnet makes the same number of r.p.m. by reason of magnetic coupling, but all fluctuations in shaft speed cause relative motion between bar magnet and field coils, thus generating an a-c. voltage proportional to torsional-vibration velocity. Fig. 2 shows drive-shaft end, connector tip and lock-screw arrangement which obviates any need of outside wires, brushes or collector rings. —*Commercial Engineering Labs., 5612 Woodward Ave., Detroit, Mich.*

Process Timer

Originally designed for mechanical connection to the machine, improved model of "Signal-Graph" is controlled by an electric switch and may be located at any distance from the machine or other equipment. In operation, it signals the operator when the processing period for which it has been set

has elapsed. In addition it records the processing time of each operation, as well as the loading or inactive time, on a chart graduated in minutes. Being operated by a synchronous motor it measures time with the accuracy of an a-c. electric clock.—*Production Instrument Company, 702 W. Jackson Blvd., Chicago, Ill.*

RUBICON PORTABLE PRECISION POTENTIOMETER

Available in a number of double range combinations, such as 1 volt and .1 volt, 100 MV and 10 MV, also in pH ranges. Guaranteed accuracy .1%. *An outstanding value.*

Described in Bulletin 270 which also describes Rubicon High Precision Type B Laboratory Potentiometer.

We also make galvanometers, electrometers, colorimeters, permeameters, Wheatstone and Kelvin Bridges, Resistance standards, coil testers, acronographs, clip-on transformer ammeters.

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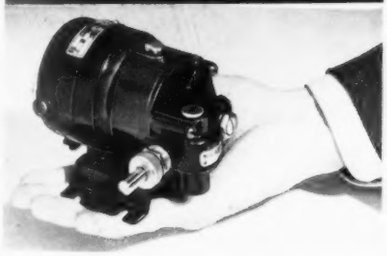

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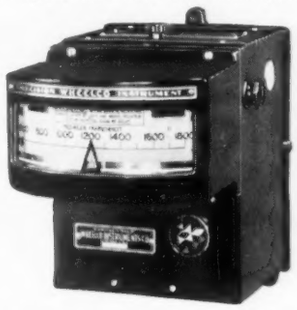
Control Potentiometers

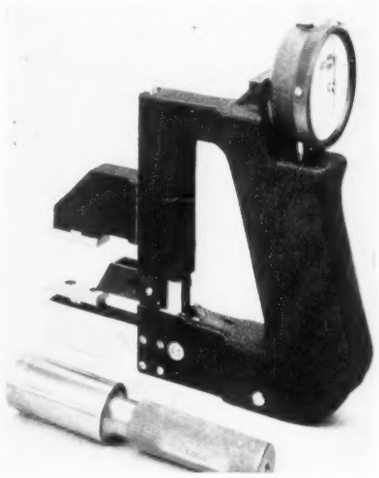
New "Series 3200" automatic controllers combine potentiometric type measuring systems and resonant-circuit type contactless control systems. Thus, automatic controller



as an assembly is purely electrical, not electro-mechanical. Only moving part of instrument is galvanometer of potentiometric circuit. This pointer carries near its tip a "flag" (tiny metallic disk), the position of which in relation to two coils in a tuned circuit determines the grid excitation of an electron tube, as in maker's original "Capacitrol" (see *Instruments*, Nov. 1935, page 364). Dimensions of flag and coils, and electrical constants of resonant circuit, are such that a 0.002" displacement of galvanometer pointer tip initiates corrective action in control circuit. A built-in bull's-eye light signals control action. Either "two-position" or "proportioning" modes of control may be obtained, the latter with adjustable ratio of potentiometer unbalance to controlled-valve position. Claim is made that absence of mechanical cycles, such as periodic clamping of a galvanometer pointer, not only obviates need of lubrication but "completely eliminates time lag between temperature deviation and control." When potentiometric measuring system is used for temperature applications with thermocouples as primary elements, an automatic cold-junction temperature compensator is included which employs the resistance-thermometer principle. —*Wheelco Instruments Co., 1933 S. Halsted St., Chicago, Ill.*

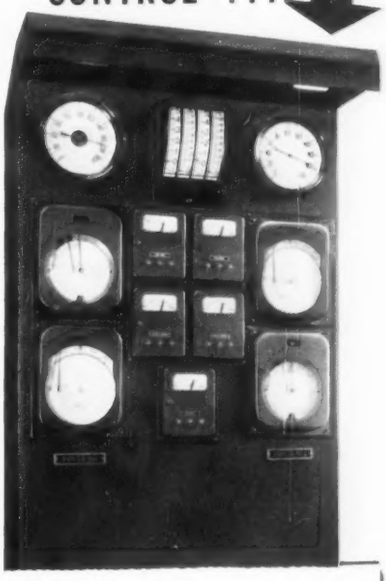
Adjustable Snap Gage

Dependence upon operator's sense of feel is obviated in new "Model 1330" adjustable snap gage. There are no levers to operate: work snaps in between contacts, against



back stop. Upper jaw is adjustable, is held rigidly; lower jaw is one end of a simple lever, other end of which contacts indicator point. Jaws have tungsten carbide inserts. Capacity: max. jaw opening, 2½"; min. jaw opening 1". Indicator range 0.2", in 0.0001". —*Federal Products Corp., 1144 Eddy St., Providence, R. I.*

HERE'S Hays CENTRALIZED COMBUSTION CONTROL ...



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COMBUSTION INSTRUMENTS AND CONTROL — MICHIGAN CITY, INDIANA, U.S.A.

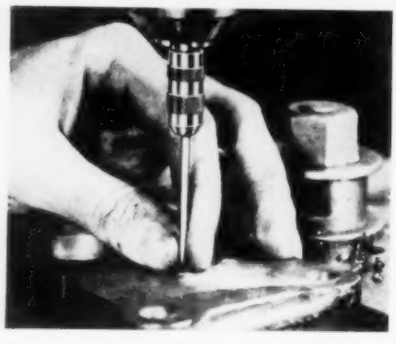
High-voltage Coil Tester

For high-speed production testing of turn-to-turn insulation, new coil tester subjects coil to many times overvoltage, operates while voltage is impressed and thus detects not only permanent failures but temporary

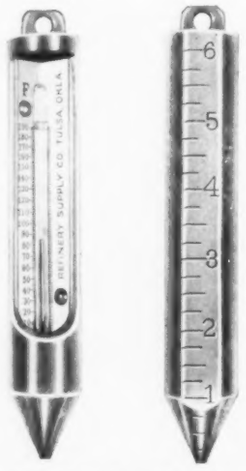
failures which might not persist after power is removed. Output of a standard vacuum-tube oscillator, supplied by a vacuum-tube rectifier designed for operation from a 115-volt 60-cycle source, excites a straight laminated core of a special high-frequency material. On either side of exciting winding are detector coils connected through a bridge circuit to a vacuum-tube voltmeter. Normally, voltages induced in detector coils are equal and voltmeter reads zero. Coil under test is placed over one end of this core and a voltage is induced in it. If a breakdown of insulation occurs, a short-circuit current flows in coil, producing a counter-mmf, and unbalancing the bridge. Equipment is mounted in a perforated steel case with all controls on front panel. A door with reinforced glass window opens into testing compartment which is lined with a fireproof insulating material. To protect operator, an interlock prevents excitation being applied with door open. Test proceding consists in placing coil over core, closing door and pushing button. "Several hundred coils an hour may be tested."—*Special Products Section, General Electric Co., Schenectady, N. Y.*

Center Finder

No. 828 "Wiggler" has been developed for jig and tool work in milling machines, drill presses and similar vertical machines where it is necessary to locate working points with



considerable accuracy. It consists of a spring-tensioned pointer held in a tapered shank with the pointer free to "wiggle". When set in chuck or tool holder, and pointer guided to true concentric, bringing working point of any job into alignment with machine spindle is simplified. Tension of spring which bears on a ball on end of pointer can be adjusted by a screw in back of shank. This spring cushions the pointer and protects it against damage or distortion if Center Finder is brought into too firm contact with work. Pointer can be telescoped into body when not in use.—*L. S. Starrett Co., Athol, Mass.*



R. S. THERMO PLUMB BOB

Consists of a regular six inch 15 ounce brass plumb bob, hollowed out and equipped with a thermometer for reading the temperature of the oil, and to insure correct temperature reading a small amount of oil is retained in bottom of plumb bob. The thermometer is supplied with two ranges, either minus 20 to 120° F. or plus 30 to 220°F. On the back of the plumb bob there is a six inch scale, which can be used to gauge the amount of water in the bottom of the tank.

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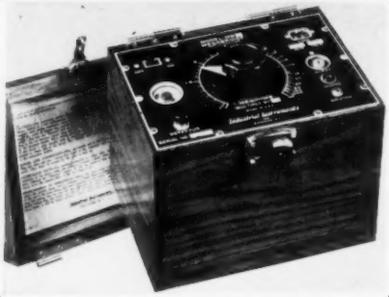
MEGABRIDGE



THE Megabridge is the most rapid device for routine insulation measurements which still retains the inherent accuracy of the Wheatstone Bridge. Operates from 110-220 volt A.C. line; available in resistance ranges up to 100,000 megohms. Ruggedly built, accurate; compact and portable.

Laboratory, production and maintenance staffs find the Megabridge invaluable. Among its many applications, it is especially useful in testing:

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Radio Components — condensers, resistors, volume controls, etc.
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Moisture Content — lumber, paper, etc.

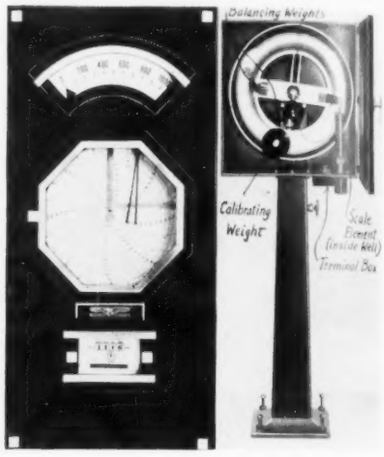
MODEL MB-2
$45.00

Write for Bulletin MB-202

Industrial Instruments, Inc.
Bayonne, N. J.

Ring-balance Flowmeter

Particularly suitable for metering gases at pressures too low for mercury-and-float U-tubes, new ring-balance meter-body is designed to give full-scale reading on differ-



entials as low as 2" water; is convertible from one scale-range to another by changing the calibrating weight; may be located remotely from pipe line and from instrument board. Welded-steel ring, 22½" o.d., partly filled with sealing-liquid to suit application, actuates variable-resistor scale element of maker's electrical telemetering system. Square-root extraction is performed by design of scale element. Maker's standard receiving instruments are available singly or in sets. New ring-balance meter-body is available for pedestal mounting (illustrated) or wall mounting.—*Republic Flow Meters Co., 2249 Diversey Parkway, Chicago, Ill.*

Solenoid Valves

Improved "Type H" solenoid valves have novel scheme for electrical connections: lower section of coil housing is empty and provides a terminal chamber into which wires are pushed after making connections. An adaptor receives a straight or angle BX

connector or conduit lock-nut. For cord connections, a porcelain bushing is inserted in adaptor. A "composition tip" in the impulse plunger and a similar stop at upper end of plunger travel are said to silence usual "click." Plug, containing seat, is removable for cleaning without disturbing electrical or pipe connections. Valves will control water, air, gas, oil, or steam. Pipe sizes ⅛", ¼", or ⅜" with 1/16", and ⅛" diameter orifices.—*Supreme Electric Products Corp., Rochester, N. Y.*

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RHEOSTATS

Jagabi Rheostat; 8 inch; wire wound. Note Bakelite sliding saddle.

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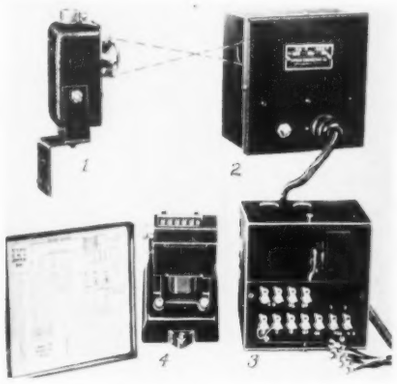
High-speed Photoelectric Counting Equipment

New combination of mostly-new units, designated as Equipment Type PC-3, is guaranteed for 600 counts per minute under the severest industrial conditions. Recommended max. speed is 20 per second. It is claimed that an $\frac{1}{8}$" interval between objects (traveling on conveyor between light-source unit and photocell-and-amplifier relay unit) is sufficient for a count, and that under ideal conditions a 0.02" interval will suffice. Moreover, new equipment includes a pc. & amp. relay unit (No. 2 on illustration) which operates either from complete on-and-off of illumination or from a 10% variation in light incident on cell. (Specifically, a variation of 0.005 lumens within the 0-0.3 lumen range.) This makes possible operation by "seeing" the illuminated objects themselves, instead of their shadows. Numerous circuits, contact arrangements, etc., are available. — *Lipman Engineering Co., 415 Van Braam St., Pittsburgh, Pa.*



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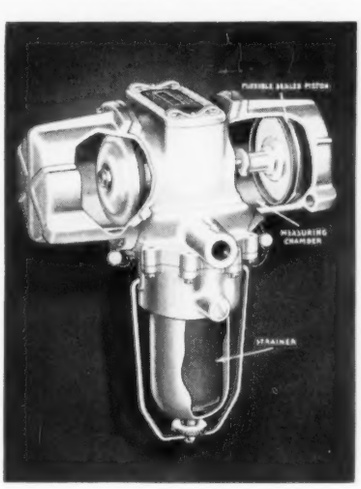
Fuel Meter; Remote Register

Primarily designed for trucks, new "Akraflo" meter is applicable wherever flow rates between 0.5 and 20 g.p.m. are to be metered, and where pressure does not exceed 5 lbs./in.². Two models: (1) self contained (illustrated) with five-digit register reading to 0.1 gal.; dimensions $8\frac{1}{2}$" × 5" × 9" high; net weight approx. 8 lbs. (2) Remote-indicating; instead of integral register, an electrically actuated round-form five-digit register $2\frac{3}{8}$" diam. which may be mounted on instrument board, furnished standard for 6-volt d.c. (other voltages on special order).—*S. F. Bowser & Co., Inc., Fort Wayne, Ind.*



CERTIFIED RESISTORS

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The calibration of the new SHALLCROSS type #245 Bifilar Manganin wire wound resistors is guaranteed to be permanent. The actual resistance is certified and permanently marked on each resistor.
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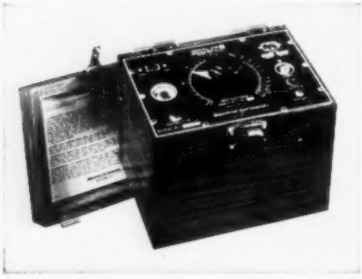
Leakage Resistance Tester

(Corrected, Discard April item)

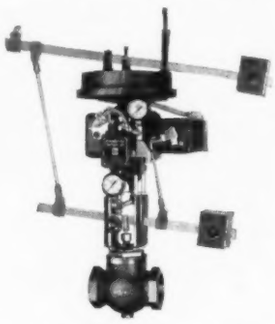
New "Series MB Megabridge" is claimed to be "the most rapid device for routine insulation tests which still retains the inherent accuracy of the Wheatstone Bridge." For



production test routine, pointer knob is set to insulation value limit, device to be tested is connected, and "detector" button is pressed: if insulation value is below standard, null indicator signals this condition. For measuring resistances, pointer is rotated until opening of null indicator remains unchanged with "detector" button depressed. Electrically, "Megabridge" is an adaptation of Wheatstone bridge, utilizing an electron-ray null indicator instead of a galvanometer. Operating from a-c. power line, it has a self-contained d-c. supply for bridge circuit and electron-ray tube. Calibration is said to be unaffected by fluctuations of line voltage or tube variations. For rapid testing of capacitors and high-capacity cables, instrument is arranged to charge capacitor automatically when connected to test terminals. High-potential terminal assembly is so guarded, it is said, that any leakage over surface of terminal insulation does not affect calibration. A third terminal is provided for use in measurements which require external guarding. Instrument is housed in a walnut cabinet, 8" × 7" × 5¾", weighs 6¼ lbs. Accuracy: "Within 1% from 1 to 15 on scale and as close as readable for remainder of range." Eight models are available, four for 50-60-cycle 115-volt supplies and four for 25-60-cycle 115-230-volt supplies, megohm ranges being 0.1 to 100, 1 to 1000, 10 to 10,000 and 100 to 100,000.—*Industrial Instruments Inc., 162 W. 23rd St., Bayonne, N. J.*

Gas-fired Boiler Control

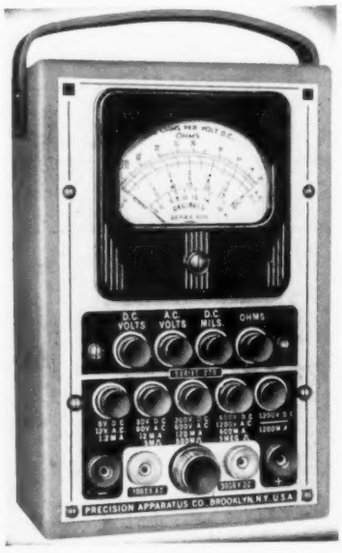
New Type V080A Combustion Regulator is designed to control steam pressure in a gas-fired boiler by controlling air supply in conjunction with gas. It can be installed to automatically fire any radiant or blue flame burner of atmospheric type. Entire assembly is mounted on gas valve bonnet at a single point; and a ¼" steam supply and exhaust line and connection to the electric service complete the installation. Although high-pressure safety is chief function of regulator, its terminal panel is arranged for easy incorporation of additional safety devices such as "Lo-Water Cutoff," "Pilot-



stat" or "Protectoglo" flame safeguard relay, for complete safety shutdown of gas valve regardless of demand on regulator at low steam pressure.—*Minneapolis-Honeywell Regulator Co., 2950 Fourth Ave. South, Minneapolis, Minn.*

Multi-range Tester

New "Series 870" is an automatic push-button a-c.d-c. multi-range tester incorporating 29 ranges including a 3,000-volt a-c.



d-c. range. All measurements, except this 3,000-volt, are obtained from two polarized tip jacks.—*Precision Apparatus Co., 821 East New York Ave., Brooklyn, N. Y.*

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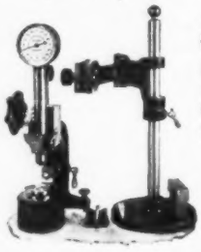

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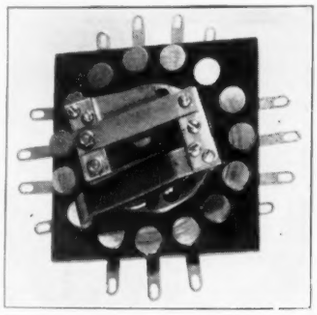
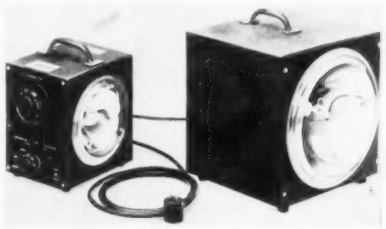
Rotary Instrument Switches

New "Type BN-15 Series" rotary instrument switches are available in numerous combinations of plate size, number of contacts and of decks, and shorting or non-shorting. Brass or silver contacts are mounted on a switch plate of Bakelite, Mycalex or steatite, together with a collector ring of steel or brass. Material of the switch plate depends upon application. Brass shaft is allowed to rotate in a brass bushing; on one end of this shaft is a strip of insulation onto which is connected two brass arms. One arm holds three phosphor-bronze strips which wipe the contacts at an angle; the other arm holds two phosphor-bronze arms or strips which wipe the collector ring to complete the circuit. Rotor is so designed that a steel ball rises and falls into countersunk holes in collector ring. Constant pressure is maintained on ball at all times to assure positive position. Such employment of collector ring and multiple-contact arms is said to assure constant and low contact resistance.—*J-B-L Instrument Co., P. O. Box 135, Darby, Pa.*



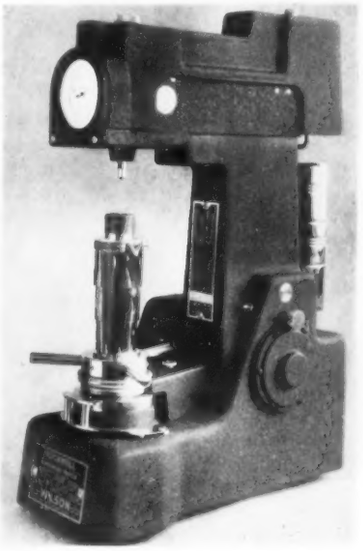
Portable Stroboscopes

Two new portable stroboscopes are suitable for both speed measurement and slow-motion studies of rotating and reciprocating mechanisms. Speed measurements with an accuracy of ±1% can be made with new "Type 631-B Strobotac" which supersedes Type 631-A. No mechanical or electrical contact with machine under measurement is required. The stroboscopic light is directed on machine and flashing rate adjusted until motion appears to be stopped. Speeds between 600 and 14,400 r.p.m. are read directly from scale conveniently located at top of instrument. Dimensions 7½" × 8¾" × 10"; weight 10 lbs. "Type 648-A Strobolux" is a larger instrument, furnishing about 100 times as much light as the Strobotac. It is used in conjunction with the Strobotac when larger areas are to be illuminated or where background lighting is strong. It can also be used as a light source for single-flash photography. Dimensions 13" × 11" × 13" overall; weight 25 lbs. Both units operate from a-c. line. The Strobotac requires 25 watts, the Strobolux 150 watts.—*General Radio Co., 30 State St., Cambridge A, Mass.*

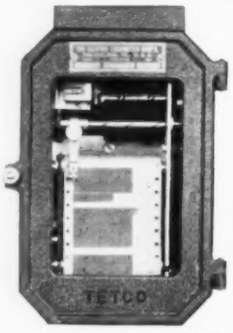


Motorized Hardness Tester

For 100% production testing of parts made in large quantity or for testing a large percentage of product, new Model QR Rockwell Hardness Tester is motorized, and available in 8" vertical capacity. Readings obtained are identical with readings obtained on Rockwell hand-operated machines. Specifications determined on the hand-operated models may therefore be met on new motorized tester. Readings are independent of variations in thickness of piece being tested.—*Wilson Mechanical Instrument Co., 383 Concord Ave., New York City.*



TETCO
Speed Recorder



Creates a permanent time record on a waxed chart. Accurately records rate of production, time and duration of stops, total quantity produced.

The Electric Tachometer Corp.
1358 Spring Garden St., Philadelphia, Pa.

Radio-servicing Vibrator and Substitute Speaker

"Model TS-50" is a new type of testing instrument said to be "the only meter-equipped universal substitute speaker and vibrator tester. Output meter is connected

to a special winding on output transformer so that it will indicate output in watts. Features include a complete "A" battery circuit for auto radio testing. Substitute speaker section includes a permanent-magnet dynamic speaker with universal output transformer for matching 2000 to 30,000 ohms.—*The Hickok Electrical Instrument Co., 10514 DuPont Ave., Cleveland, Ohio.*

Multi-purpose Watch

New "No. 460 Multi-Purpose Chronograph" performs following functions: (1) timepiece of wristwatch form with 17-jewel non-magnetic Swiss movement encased in stainless alloy; (2) stop-watch measuring seconds and fifths up to total of 12 hours; (3) "tachometer" indicating miles-per-hour over known distance; (4) twelve-hour "time-out" watch with one button consecutively starting, stopping and again starting sweep second hand and other button for flyback; (5) "telemeter" which gives distance by interval between light and sound from simultaneous sources. Other features are the separate-dial 30-min. and 12-hr. registers and the retention of the 60-sec. continuously-operating dial.—*Jardur Import Co., 21 West 19th St., New York City.*

Illuminator Magnifier

New "Magnalite" combines light source said to concentrate "daylight" on object being inspected, and magnifier. This assembly may be used with stand as illustrated, or detached therefrom.—*Mizzy, Inc., 104 E. 16th St., New York City.*

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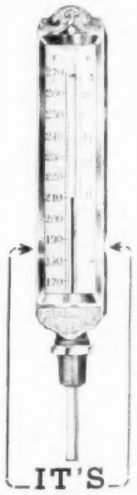

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Manufacturers: All types—High-grade Thermometers
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General Principles of Instrument Analysis

By C. S. DRAPER and G. V. SCHLIESTETT

Massachusetts Institute of Technology

INSTRUMENTS have come to play such a large part in the industrial life of our times that a specialized branch of engineering has developed under the accepted title of Instrumentation. Instruments may be and frequently are so complex that the time and effort involved in a complete theoretical treatment would not be justified. Generally speaking, however, most instrument problems are similar in that any case, reduced to the simplest terms, comprises some sort of "pointer" driven by a force which is a function of that-which-is-measured; or simply, *an indicating element* responding to *a measurable magnitude*. This means that an *elementary instrument* is essentially a system with one degree of freedom and can be studied by the well-known methods already developed for such systems. The present paper outlines the method of attack used at M.I.T. to systematize and simplify the study of instrument problems. An extension of this work to include automatic-control systems is now under way and has already resulted in an introductory article.[1]

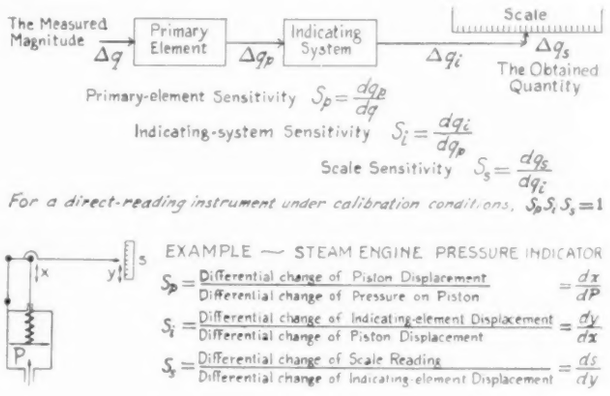

The Measured Magnitude
Δq
Primary Element
Δqp
Indicating System
Δqi
Scale
Δqs
The Obtained Quantity
Primary-element Sensitivity Sp = dqp/dq
Indicating-system Sensitivity Si = dqi/dqp
Scale Sensitivity Ss = dqs/dqi
For a direct-reading instrument under calibration conditions, SpSiSs = 1
EXAMPLE — STEAM ENGINE PRESSURE INDICATOR
Sp = Differential change of Piston Displacement / Differential change of Pressure on Piston = dx/dP
Si = Differential change of Indicating-element Displacement / Differential change of Piston Displacement = dy/dx
Ss = Differential change of Scale Reading / Differential change of Indicating-element Displacement = ds/dy
x
y
s
P

Fig. 1. Functional division of an elementary instrument.

Elementary Instruments

Instrument analysis of any sort has for its object the calculation of performance for one of the following reasons: to aid in planning a design, to determine the suitability of a certain instrument for a given job, or to correct actual readings for errors from various sources. If a single nomenclature and type of analysis can be generalized to include many apparently dissimilar cases, both the discussion and solution of such problems will be facilitated. It is therefore convenient to consider any instrument, however complicated, as made up of one or more *elementary instruments* each of which is essentially a system with one degree of freedom. To still further simplify the treatment, each elementary instrument is split up into three parts. These three parts can be taken as:

1. The *primary element* which receives changes in some measurable magnitude and transforms these changes into a force suitable for operating an indicating mechanism.

2. The *indicating system*, which takes the output of the primary element and produces a change in some *indicating element*, which change can be observed or recorded with the required degree of accuracy.

3. The *scale*, which associates any change in the indicating element with the corresponding change in the measured magnitude.

It is to be noted that this division is functional rather than physical and it is thus possible for a single part to act in more than one capacity at the same time. On the other hand, the component parts of an elementary instrument may be widely separated in space. For example the primary element of a radio-meteorograph may be many thousand feet in the air. The indicating system includes a radio sending set which commands a receiving set and recording device on the ground.

A block diagram showing the division of an elementary instrument into its component parts is shown in Fig. 1. The steam engine indicator is used as an illustration in this figure. Pressure applied to the lower side of the piston compresses the spring and thus produces motion of the rod connected to the piston. The cylinder, piston and spring assembly thus act as a unit to convert pressure changes into changes of position of the piston rod. Motion of the piston rod is received by a lever which in turn moves an indicating element along a drum. The linkage which thus transmits the motion is the indicating system. The scale which makes it possible to interpret indicating-element position in terms of pressure could be printed directly on the indicator paper but is usually applied by means of a specially graduated ruler.

Specification of Performance

The behavior of any elementary instrument is known if the ratio of output to input of each of the three component parts is specified. Such ratios fit in with common-sense ideas of sensitivity, that is, in comparing two primary elements it is natural to judge one primary element twice as sensitive as the other if it gives twice the output for a given change in the measured magnitude. Similarly, the most sensitive indicating system is that which gives the greatest change in the indicating-element position for a given input from the primary element. In terms of symbols the three sensitivities can be expressed as

$$S_p = dq_p/dq = \text{primary-element sensitivity} \quad (1)$$

$$S_i = dq_i/dq_p = \text{indicating-system sensitivity} \quad (2)$$

$$S_s = dq_s/dq_i = \text{scale sensitivity} \quad (3)$$

where q denotes the measured magnitude, q_p is the output of the primary element, q_i is the indicating-element position, and q_s is the *obtained quantity*, or the *scale reading*, in terms of the measured magnitude.

When the scale of the elementary instrument is properly marked and the instrument is operating under *calibration conditions* or has proper provisions for compensation, the change in scale reading will be equal to the change in the measured magnitude which produced the change in indicating-element position. From this it follows that for a perfectly calibrated elementary instrument

$$S_pS_iS_s = 1 \quad (4)$$

This relationship sums up the requirements for a direct-reading instrument and is convenient for generalized design

EDITOR'S NOTE

At the recent C.I.T. Instrumentation Conference, Professor Draper presented a summary of this paper (then uncompleted). None of us listeners had any previous inkling of its nature. Some of us expected a "sterile pedagogic dissertation." A few minutes later we were being thrilled. When Draper sat down and the Chairman called on me, I could only paraphrase what a famous mathematician said on a somewhat similar occasion: **"To estimate the value of their treatment is as much beyond me as the value of their treatment is beyond that of mine."** . . . And because I consider it of great and lasting importance as a text, I subjected the author's manuscript (and some illustrations) to numerous drastic revisions. The authors graciously agreed to all, except for two of the changes in terminology, which they ask me to disclose here. These are: (1) the terms "measurable magnitude" and "measured magnitude" as printed, for their term **"actuating quantity"** and (2) the term "primary element" as printed, for their term **"converter."**—M. F. Béhar

purposes. However, Eq. (4) is never exactly true for an actual instrument on account of errors inherent in the mechanism or because of changes in physical conditions other than the measured magnitude. Thus for practical cases

$$dq_s = S_p S_i S_s\ dq = C\ dq \qquad (5)$$

where C *is the calibration coefficient*, by means of which errors of all kinds are accounted for in an elementary instrument.

Although an ideal instrument would be sensitive only to the magnitude that it was designed to measure, it is unfortunately true that instrument mechanisms are often sensitive to changes in other magnitudes. This means that the sensitivity of each component is subject to variations due to these changes, or stated mathematically

$$S_p = f_1\ (q, p_1, p_2, p_3\ \ldots\ldots) \qquad (6)$$

$$S_i = f_2\ (q, p_1, p_2, p_3\ \ldots\ldots) \qquad (7)$$

$$S_s = f_3\ (q, p_1, p_2, p_3\ \ldots\ldots) \qquad (8)$$

$$C = f\ \ (q, p_1, p_2, p_3\ \ldots\ldots) \qquad (9)$$

where p_1, p_2, p_3 ..... are independent physical magnitudes other than q. This mathematical statement is equivalent to the differential equation

$$dq_s = (\partial q_s/\partial q)\ dq + (\partial q_s/\partial p_1)\ dp_1 + (\partial q_s/\partial p_2)\ dp_2 \ldots (10)$$

If the physical magnitudes p_1, p_2, etc. are constant or if the coefficients $\partial q_s/\partial p_1$, $\partial p_s/\partial q_2$, etc., are sufficiently small, the change in q_s depends only upon the change in q and the coefficient $\partial q_s/\partial q$ becomes identical with the total differential dq_s/dq which is the calibration coefficient C.

Calibration and Errors

Practical situations usually require readings expressed in terms of the value of the measured magnitude. To find this value the differential changes must be integrated to obtain

$$q_s = \int dq_s = \int C\ dq = C\ q + \text{Constant} \qquad (11)$$

where C is the average value of the calibration coefficient over the range of values involved. The constant of integration is usually made to vanish by the way the scale is laid out and by the zero adjustment of the instrument. Instead of expressing deviations of an instrument from perfect performance by means of the multiplying factor C it is often more convenient to apply an additive term based on the assumption that the calibration coefficient is unity, *i.e.*,

$$q = q_s + q_{corr} \qquad (12)$$

where q_{corr} is the correction which must be applied to the scale reading in order to obtain the true value of the measured magnitude.

One troublesome source of error in mechanical instrument systems is rubbing friction between solid parts (Coulomb friction). Friction of this nature tends to be erratic in its effects and always resists relative motion between parts in contact. Thus the indicating element of an instrument in which friction is a factor will not move at all until the change in the measured magnitude has built up some minimum *driving force*, and even after the sticking parts have broken loose the motion is likely to be unsteady. It is so difficult to determine the effects of rubbing friction that an instrument in which considerable errors of this nature exist will be considered as requiring repairs and ruled out of further consideration.

Dynamic Errors of an Elementary Instrument

Static conditions have been tacitly assumed in the preceding discussion, that is, readings were considered only when the measured magnitude and indicating-element position had both become constant after a change. Actually the indicating element of any elementary instrument will not follow changes in the measured magnitude exactly if these changes occur too rapidly. Inaccuracies in the indications of an elementary instrument peculiarly due to the fact that the measured magnitude is changing with time are called *dynamic errors*.

The engine indicator of Fig. 1 is a typical example of an elementary instrument subject to dynamic errors. This instrument has already been analyzed and the results are available in the literature.[2,3] All of the typical forces which ordinarily occur in instrument problems are involved so the engine indicator will be used to illustrate ideas which can be directly applied to any instrument. An analysis requires a knowledge not only of the physical properties of the mechanism but also the manner in which the measured magnitude varies with time. It will be found that a study of the way in which the instrument responds to a *step function*, *i.e.*, a sudden change of the *driving force* (the utilized effect of the measured magnitude) between two constant values, will immediately give all the necessary experimental data. The general procedure is to start with the differential equation of motion for the moving parts of the instrument and to derive an expression for the variation of scale readings with time when the driving force changes in a given manner. The difference between values of the scale reading and the driving force will be the dynamic error at any instant.

Forces of four types act on the piston and indicating system of the engine indicator selected for illustration.

1. Inertia force expressible as $-m\,d^2x/dt^2$
2. Friction force approximated by $-c\,dx/dt$
3. Elastic force given by $-k\,x$
4. Driving force due to pressure on the piston given by AP.

The first of these expressions must be corrected for the fact that the mass m is not the simple mass of the piston and rod but is an *equivalent mass* taking into account the parts of the spring and indicating system which move when the piston moves. Similarly the friction force may not be exactly proportional to the piston velocity, as it should be if all parts were separated by oil films, but may vary from this simple law on account of rubbing friction between solid parts. For this reason the value of the damping coefficient c must be considered as an effective value. With a properly designed spring, the elastic force acting on the moving system will be closely proportional to the displacement x of the piston from a proper zero point so the elasticity coefficient k can usually be taken as constant. With a piston-and-cylinder system the area A of the piston will be substantially constant under working conditions so no approximation is introduced by the driving force term.

Summing up the various forces and dividing through by the mass m gives as the equation of motion for the indicator piston system

$$d^2x/dt^2 + (c/m)\ dx/dt + (k/m)\ x = (A/m)P \qquad (13)$$

Over a sufficiently small range of deflections, the coefficients (c/m), (k/m) and (A/m) can be taken as constant. It is convenient to limit consideration to such a range since the solutions of Eq. (13) then have well-known simple forms. In spite of the approximations involved it is usually better in practice to accept the inaccuracies of an easily handled mathematical form than to attempt more difficult exact solutions. Whether or not the simple solutions will be satisfactory in a given instance can be determined only by study of the particular case.

The solution of Eq. (13) is an expression giving the variation of q_s with time. This solution is mathematically separable into two parts:

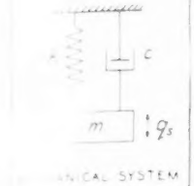
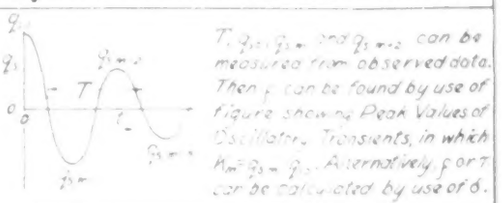
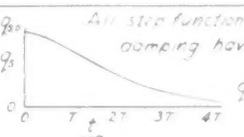
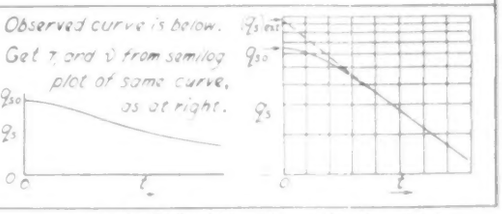
1. The *transient* which depends upon the engine indicator, the state of motion of the piston at the instant chosen as zero on the time scale and the manner in which the driving force varies with time.

2. The *steady-state solution* which depends only upon the indicator and the *forcing function*, *i.e.*, the law which expresses the change of driving force with time.

On the physical side, the steady state solution corresponds to the behavior of the piston under a forcing function which continues indefinitely while the transient represents the period of accommodation required by the engine indicator to go from one steady state condition to another.

A simpler case than that of Eq. (13) is found in thermometers used to measure fluid temperatures. Such instruments usually have dynamic errors depending upon the rate at which the average temperature of the primary element (say a mercury-filled bulb), or, more precisely, the average temperature of the mercury inside the bulb, follows temperature fluctuations in the fluid. If heat flow to the primary

TRANSIENTS IN AN ELEMENTARY INSTRUMENT

CASE OR CONDITION	EQUATION OF MOTION	DEFINITIONS OF SYMBOLS	SOLUTION OF EQUATION	MEASURABLE DATA
GENERAL  MECHANICAL SYSTEM ITS ANALOGUE	$m\ddot{q}_s + c\dot{q}_s + kq_s = 0$ $\ddot{q}_s + 2\zeta\omega_n\dot{q}_s + \omega_n^2 q_s = 0$ $\ddot{q}_s + \frac{2}{\tau}\dot{q}_s + \omega_n^2 q_s = 0$	m = mass coefficient c = damping coefficient k = elasticity coefficient q_s = scale reading ζ = damping ratio = c/c_c $\omega_n = 2\pi$ (undamped nat. freq) $\zeta = c/2\sqrt{km}$ $\omega_n = \sqrt{k/m}$ $\tau = 2m/c$ $i = \sqrt{-1}$ $\frac{1}{\tau_1} = \frac{1}{\tau} - i\omega$ $\frac{1}{\tau_2} = \frac{1}{\tau} + i\omega$ $\omega = \sqrt{k/m - (c/2m)^2} = \omega_n\sqrt{1-\zeta^2}$	$q_s = Ae^{-t/\tau_1} + Be^{-t/\tau_2}$	The fitting constants A, B, C and ϕ must be given values to fit each case at hand. The method of doing this is to substitute the measured or calculated initial conditions of q_{s0} and $\dot{q}_{s0}$ at time $t = 0$. The data in the colum below pertain to response of an indicating element after application of a step function, i.e., after a sudden change in the measured magnitude from one constant value to another.
CASE I OSCILLATORY $k/m > (c/2m)^2$ $\zeta < 1$ $\omega < \omega_n$ ν is complex	$\ddot{q}_s + 2\zeta\omega_n\dot{q}_s + \omega_n^2 q_s = 0$ $\ddot{q}_s + \frac{2}{\tau}\dot{q}_s + \omega_n^2 q_s = 0$ $\ddot{q}_s + \frac{2\delta}{\tau}\dot{q}_s + \frac{4\pi^2+\delta^2}{\tau^2}q_s = 0$	δ = logarithmic decrement $= \ln\frac{q_{s_m}}{q_{s_{m+2}}} = \ln\frac{K_m}{K_{m+2}}$ $\tau = T/\delta$ m = peak number $\zeta = \frac{\delta}{\sqrt{4\pi^2+\delta^2}} = \frac{1}{\tau\omega_n} = \frac{\delta}{2\pi}\frac{T_0}{T}$	GENERAL FOR CASE I $q_s = Ae^{\alpha t}\cos\omega t + Be^{\alpha t}\sin\omega t = Ce^{\alpha t}\cos(\omega t - \phi)$ STEP FUNCTION FOR CASE I $q_s = q_{s0}\cos\frac{2\pi t}{T} + \frac{\zeta}{\sqrt{1-\zeta^2}}\sin\frac{2\pi t}{T}e^{-\frac{2\pi\zeta}{\sqrt{1-\zeta^2}}\frac{t}{T}}$ $q_s = q_{s0}\frac{\cos\frac{2\pi t}{T} - \sin\frac{2\pi t}{T}}{\sqrt{1-\zeta^2}}e^{-\frac{2\pi\zeta}{\sqrt{1-\zeta^2}}\frac{t}{T}}$	 T, q_{s0}, q_{s_m} and $q_{s_{m+2}}$ can be measured from observed data. Then ζ can be found by use of figure showing Peak Values of Oscillatory Transients, in which $K_m = q_{s_m} - q_{s_\infty}$. Alternatively ζ or T can be calculated by use of δ.
CASE II CRITICALLY APERIODIC $k/m = (c_c/2m)^2$ $\zeta = \nu = 1$ $\omega = 0$	$\ddot{q}_s + \frac{2}{\tau}\dot{q}_s + \frac{1}{\tau^2}q_s = 0$	$\tau = 2m/c_c = 1/\omega_n = \sqrt{m/k}$ c_c = critical damping coeff	GENERAL FOR CASE II $q_s = (A + Bt)e^{t/\tau}$ STEP FUNCTION FOR CASE II $q_s = q_{s0}(1 + t/\tau)e^{-t/\tau}$	 All step function transients for critical damping have following points in common. t/τ 1 2 3 4 q_s/q_{s0} 0.735 0.406 0.199 0.092
CASE III NONOSCILLATORY $k/m < (c/2m)^2$ $\zeta > 1$ $\nu > 1$ ω is complex	$\ddot{q}_s + (\frac{1}{\tau_1} + \frac{1}{\tau_2})\dot{q}_s + \frac{1}{\tau_1\tau_2}q_s = 0$ $\ddot{q}_s + \frac{\nu+1}{\tau_1}\dot{q}_s + \frac{\nu}{\tau_1^2}q_s = 0$	$\nu = \tau_1/\tau_2$ where $\tau_1 > \tau_2$ $\tau_1 = \frac{t_2 - t_1}{\ln(q_s)_1 - \ln(q_s)_2}$ $\nu = \frac{(q_s)_{ext}}{(q_s)_{ext} - q_{s0}}$ $\zeta = (1+\nu)/2\sqrt{\nu}$ $\nu = 2\zeta^2 - 1 + 2\zeta\sqrt{\zeta^2-1}$	GENERAL FOR CASE III $q_s = Ae^{-t/\tau_1} + Be^{-\nu t/\tau_1}$ STEP FUNCTION FOR CASE III $q_s = q_{s0}\frac{\nu}{\nu-1}(e^{-t/\tau_1} - \frac{1}{\nu}e^{-\nu t/\tau_1})$	Observed curve is below. Get τ_1 and ν from semilog plot of same curve, as at right. 

M I T INSTRUMENT LAB 2 20 39 G V S

Chart I

element by radiation and conduction through the supporting structure is made negligibly small by proper design, the relationship between fluid temperature and primary-element temperature can be written[4, 5, 6] as

$$(s\,\rho\,V)\,dT_p/dt = A\,h\,(T - T_p) \qquad (14)$$

where

T = temperature of the fluid

T_p = temperature of the primary element

h = coefficient of heat transfer across the fluid film on the outside of the bulb.[7] (This must be a proper average value.)

A = area of bulb exposed to the heat transfer from the fluid

V = total volume of the primary element (bulb + mercury)

ρ = average density of the primary element

s = average specific heat of the primary element.

It is important to note that Eq. (14) will be true only if all parts of the primary element have the same temperature. Any instance in which this condition is not fulfilled will have to be treated as a special case.

It is convenient to write Eq. (14) in the form

$$dT_p/dt + T_p/\tau = T/\tau \qquad (15)$$

where $\tau = (s\,\rho\,V)/(A\,h)$

In Eq. (15) τ has the dimensions of time and is called the *characteristic time* (some writers call it the thermometric lag coefficient). In a particular case this characteristic time depends upon the material and construction of the primary element and conditions in the fluid in contact with the primary element. This means that for a particular value of τ Eq. (15) can be applied only to a limited range of temperature, fluid velocity, etc.

Ordinarily the indicating element of a thermometer will respond so rapidly that dynamic errors from this source are negligibly small. It follows that the scale reading of a properly calibrated thermometer will be substantially equal to the primary-element temperature. Within a properly limited range of conditions the thermometer readings will follow time variations in fluid temperature in a manner given by the solution of Eq. (15). In any given case this solution will consist of a transient part and a steady-state part just as in the more complicated case of Eq. (13).

Transients

Sudden changes in the forcing function applied to an elementary instrument, whose response can be expressed in a form similar to Eq. (13), will in some cases produce damped oscillations of the indicating element at the natural frequency of the moving system, while in other cases the effect will be an additional non-oscillatory component in the dynamic error which disappears after a sufficiently long time has elapsed. Corresponding to this physical difference between transients, the mathematical expressions for transient motion separate into *oscillatory* cases and *non-oscillatory* cases. The dividing-line case between these two types is referred to as *critically aperiodic*. Systems which behave according to the thermometer equation (Eq. 15) will never have oscillatory transients.

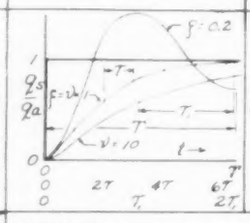
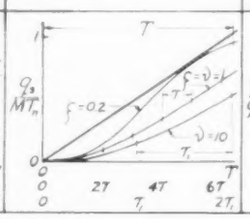
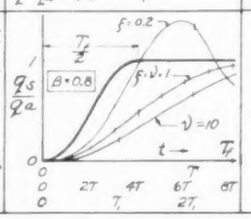
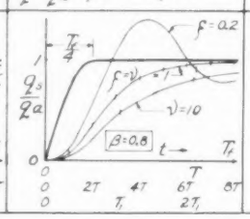
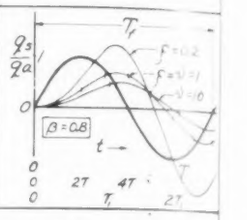
Expressions for the transient are found by solutions of Eq. (13) with the term on the right-hand side placed equal to zero. The methods required for this solution are conventional and the results are well-known, so the mathematical details will be omitted here.

Practically, it is easier to study the transient response of an engine indicator in terms of the scale reading than in terms of the motion of some internal part. For this reason it is convenient to use the sensitivity relationships and write Eq. (13) in the form

$$dP_s/dt^2 + (c/m)dP_s/dt + (k/m)P_s = (k/m)S_pS_vS_iP \qquad (16)$$

where the product of the three sensitivities is equal to unity in a properly calibrated instrument. If the problem is one of design, values of m, c and k will be chosen to give the desired characteristics, but if the engine indicator is available as a complete instrument, performance can be more conveniently specified in terms of the *damping ratio* ζ and the

RESPONSE OF AN ELEMENTARY INSTRUMENT TO REPRESENTATIVE FORCING FUNCTIONS

EQUATION OF FORCING FUNCTION	STEP FUNCTION $q = q_a$	LINEAR CHANGE $q = Mt$	COSINE CHANGE TO CONSTANT $q = (q_a/2)(1-\cos\omega_f t)$ for $t<T_f/2$; $q=q_a$ for $t>T_f/2$	SINE CHANGE TO CONSTANT $q = q_a \sin\omega_f t$ for $t<T_f/4$; $q=q_a$ for $t>T_f/4$	SINUSOIDAL OSCILLATION $q = q_a \sin\omega_f t$
SHAPE OF FORCING FUNCTION CURVE & TYPICAL RESPONSE CURVES FOR THE THREE CONDITIONS OF DAMPING					
	RESPONSE EQUATIONS — FORCING FUNCTION SHOWN BY HEAVY LINE IN EACH FIGURE				
CASE I OSCILLATORY $\zeta < 1$	$\frac{q_s}{q_a} = 1 - e^{-\frac{2\pi\zeta}{\sqrt{1-\zeta^2}}\frac{t}{T}}\left\{\cos\left(2\pi\frac{t}{T}\sqrt{1-\zeta^2}\right) - \frac{\sin\left(2\pi\frac{t}{T}\sqrt{1-\zeta^2}\right)}{\sqrt{1-\zeta^2}}\right\}$	$\frac{q_s}{MT_n} = \frac{1}{\sqrt{1-\zeta^2}}\frac{t}{T} - \frac{\zeta}{\pi} + e^{-\frac{2\pi\zeta}{\sqrt{1-\zeta^2}}\frac{t}{T}}\left\{\frac{\zeta}{\pi}\cos 2\pi\frac{t}{T} + \frac{2\zeta^2-1}{2\pi\sqrt{1-\zeta^2}}\sin 2\pi\frac{t}{T}\right\}$	FOR $t<T_f/2$: $\frac{q_s}{q_a/2} = 1-\mu\cos\left(2\pi\frac{t}{T_f}-\phi\right) + e^{-\frac{2\pi\zeta}{\beta}\frac{t}{T_f}}\left\{(\mu\cos\phi-1)\cos\frac{2\pi\sqrt{1-\zeta^2}}{\beta}\frac{t}{T_f} + \left(\frac{\zeta\mu\cos\phi-\zeta+\mu\beta\sin\phi}{\sqrt{1-\zeta^2}}\right)\sin\frac{2\pi\sqrt{1-\zeta^2}}{\beta}\frac{t}{T_f}\right\}$	$\frac{q_s}{q_a} = \mu\sin\left(2\pi\frac{t}{T_f}-\phi\right) + \mu e^{-\frac{2\pi\zeta}{\beta}\frac{t}{T_f}}\left\{\sin\phi\cos\frac{2\pi\sqrt{1-\zeta^2}}{\beta}\frac{t}{T_f} + \left(\frac{\zeta\sin\phi-\beta\cos\phi}{\sqrt{1-\zeta^2}}\right)\sin\frac{2\pi\sqrt{1-\zeta^2}}{\beta}\frac{t}{T_f}\right\}$
CASE II CRITICALLY APERIODIC $\zeta = \nu = 1$	$\frac{q_s}{q_a} = 1 - e^{-t/T}\left(1 + t/T\right)$	$\frac{q_s}{MT_n} = \frac{1}{2\pi}\frac{t}{T} - \frac{1}{\pi} + e^{-t/T}\left(\frac{1}{\pi} + \frac{t}{2\pi}\frac{t}{T}\right)$	FOR $t<T_f/2$: $\frac{q_s}{q_a/2} = 1-\mu\cos\left(2\pi\frac{t}{T_f}-\phi\right) + e^{-\frac{2\pi}{\beta}\frac{t}{T_f}}\left\{\mu\cos\phi-1+(\mu\cos\phi-1+\mu\beta\sin\phi)\frac{2\pi}{\beta}\frac{t}{T_f}\right\}$	$\frac{q_s}{q_a} = \mu\sin\left(2\pi\frac{t}{T_f}-\phi\right) + e^{-\frac{2\pi}{\beta}\frac{t}{T_f}}\left\{\sin\phi+(\sin\phi-\beta\cos\phi)\frac{2\pi}{\beta}\frac{t}{T_f}\right\}$ FOR SINE CHANGE TO CONSTANT, THESE EQUATIONS ARE USED ONLY FOR $t<T_f/4$ IN ALL CASES.
CASE III NONOSCILLATORY $\zeta > 1$, $\nu > 1$	$\frac{q_s}{q_a} = 1 - e^{-t/T_1}\left(\frac{\nu}{\nu-1}\right) + e^{-\nu t/T_1}\left(\frac{1}{\nu-1}\right)$	$\frac{q_s}{MT_n} = \frac{\sqrt{\nu}}{2\pi}\frac{t}{T_1} - \frac{\nu+1}{2\pi\sqrt{\nu}} + e^{-t/T_1}\left(\frac{\nu}{\nu-1}\right)\frac{\sqrt{\nu}}{2\pi} + e^{-\nu t/T_1}\left\{\frac{1}{2\pi(\nu-1)\sqrt{\nu}}\right\}$	FOR $t<T_f/2$: $\frac{q_s}{q_a/2} = 1-\mu\cos\left(2\pi\frac{t}{T_f}-\phi\right) + e^{-\frac{2\pi t}{\beta\sqrt{\nu}}\frac{t}{T_f}}\left\{\frac{\nu\mu\cos\phi-\nu+\beta\mu\sqrt{\nu}\sin\phi}{\nu-1}\right\} + e^{-\frac{2\pi\sqrt{\nu}}{\beta}\frac{t}{T_f}}\left\{\frac{1-\mu\cos\phi-\beta\mu\sqrt{\nu}\sin\phi}{\nu-1}\right\}$	$\frac{q_s}{q_a} = \mu\sin\left(2\pi\frac{t}{T_f}-\phi\right) + e^{-\frac{2\pi t}{\beta\sqrt{\nu}}\frac{t}{T_f}}\left\{\frac{\nu\sin\phi-\beta\sqrt{\nu}\cos\phi}{\nu-1}\right\} + e^{-\frac{2\pi\sqrt{\nu}}{\beta}\frac{t}{T_f}}\left\{\frac{\beta\sqrt{\nu}\cos\phi-\sin\phi}{\nu-1}\right\}$

$\mu = \frac{1}{\sqrt{(1-\beta^2)^2+(2\zeta\beta)^2}}$ $\quad \phi = \tan^{-1}\frac{2\zeta\beta}{1-\beta^2}$ $\quad \beta = \frac{\omega_f}{\omega_n}$ $\quad \omega_f = \frac{2\pi}{T_f}$ $\quad \omega_n = \frac{2\pi}{T_n} = \frac{2\pi}{\sqrt{1-\zeta^2}\,T} = \frac{1}{\zeta T} = \frac{\sqrt{\nu}}{T_1}$

Other symbols are defined in Chart I. Functions μ and ϕ are plotted in accompanying figure.

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Chart II

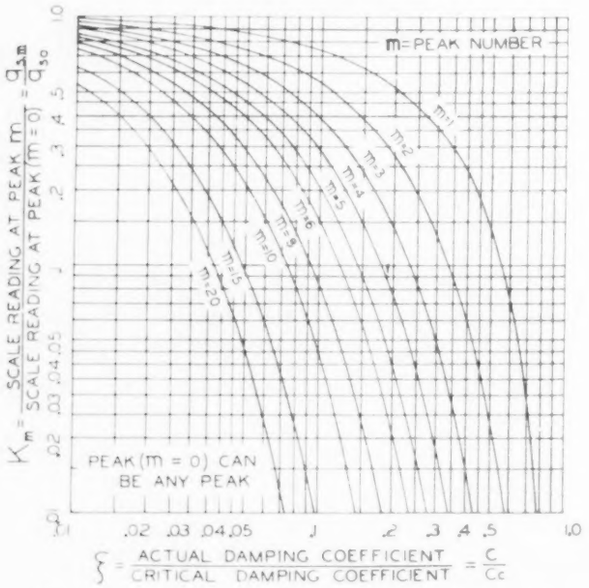


Fig. 2. Peak values of oscillatory transients as functions of the damping ratio.

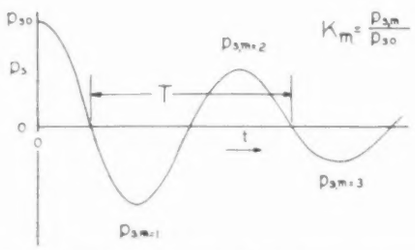


Fig. 3. Oscillatory response of an engine indicator after application of a forcing function.

undamped natural circular frequency ω_n. When these latter quantities are used, Eq. (16) becomes

$$d^2P_s/dt^2 + (2\zeta\omega_n)\,dp_s/dt + \omega_n^2 P_s = \omega_n^2 P \qquad (17)$$

It is obvious that the steps discussed above can be carried out for any elementary instrument to give a differential equation similar to Eq. (17) involving the measured magnitude, the scale reading and the characteristic coefficients ζ and ω_n. When the characteristic coefficients have been determined it becomes possible to analyze instrument behavior under any type of forcing function that can be handled mathematically. A convenient method for finding the characteristic coefficients is to study instrument response to a step function. Chart I defines the quantities involved, summarizes the equations and explains the methods required to handle any case which may occur. Fig. 2 shows a set of curves which are useful for the interpretation of oscillatory transients. In this figure, ratios between the amplitude of the transient at the mth peak to the amplitude at the peak selected as the initial peak are used as ordinates and values of the damping ratio ζ are the abscissae. The curves are drawn for various integral values of the peak number m.

Fig. 3 is part of an experimentally determined transient following a sudden change in applied pressure on an engine indicator. This curve will be used as an example of the method for finding ζ and ω_n. By measurement, the ratio between the reading at any peak to the reading at the peak one cycle earlier is $K_2 = 0.54$. From Fig. 2 the curve for $m = 2$ crosses the 0.54 ordinate at $\zeta = 0.1$ and the damping ratio is thus immediately determined. The actual period T of the free oscillation can be taken directly from the response curve as the interval between successive points where the curve crosses the equilibrium pressure line with slopes of the same sign. With T determined, ω_n can be found

RESPONSE OF A THERMOMETER TO REPRESENTATIVE FORCING FUNCTIONS

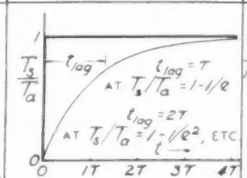
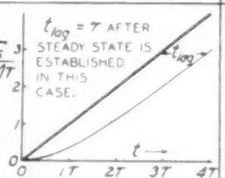
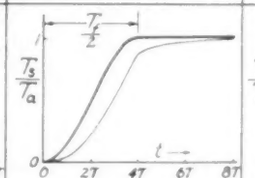
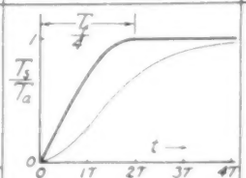
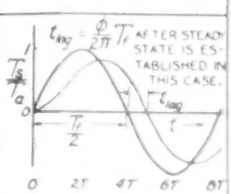
EQUATION OF FORCING FUNCTION	STEP FUNCTION	LINEAR CHANGE	COSINE CHANGE TO CONSTANT	SINE CHANGE TO CONSTANT	SINUSOIDAL OSCILLATION
	$T = T_a$	$T = Mt$	$T = (T_a/2)(1-\cos\omega_f t)$ for $t < T_f/2$ $T = T_a$ for $t > T_f/2$	$T = T_a \sin\omega_f t$ for $t < T_f/4$ $T = T_a$ for $t > T_f/4$	$T = T_a \sin\omega_f t$
SHAPE OF FORCING FUNCTION CURVE & RESPONSE CURVE. FORCING FUNCTION SHOWN BY HEAVY LINE IN EACH FIGURE.					
RESPONSE EQUATION	$\frac{T_s}{T_a} = 1 - e^{-t/\tau}$	$\frac{T_s}{MT} = \frac{t}{\tau} - 1 + e^{-t/\tau}$	FOR $t < T_f/2$ THE EQUATION IS $\frac{T_s}{T_a/2} = 1 - \mu\cos\left(\frac{2\pi t}{T_f} - \phi\right) + e^{-t/\tau}(\mu\cos\phi - 1)$ FOR $t > T_f/2$ THE STEP FUNCTION APPLIES		IN THE CASE OF SINUSOIDAL OSCILLATION THE COMPLETE EQUATION IS $\frac{T_s}{T_a} = \mu\sin\left(\frac{2\pi t}{T_f} - \phi\right) + e^{-t/\tau}\mu\sin\phi$ IN THE CASE OF SINE CHANGE TO CONSTANT THIS EQUATION HOLDS ONLY FOR $t < T_f/4$
EXTENT TO WHICH RESPONSE CURVES ARE APPLICABLE.	RESPONSE TO EACH OF THESE STEP FUNCTIONS IS SAME FOR ALL THERMOMETERS SATISFYING THE EQUATION $\frac{dT_s}{dt} + \frac{T_s}{\tau} = \frac{T}{\tau}$		RESPONSE TO EACH OF THESE STEP FUNCTIONS IS TYPICAL FOR ALL THERMOMETERS SATISFYING THE EQUATION $\frac{dT_s}{dt} + \frac{T_s}{\tau} = \frac{T}{\tau}$	THESE PARTICULAR EXAMPLES ARE FOR A FORCING FREQUENCY THAT ESTABLISHES THE RELATION $\omega_f \tau = 0.8$	
DEFINITIONS	T_s = SCALE READING OF THERMOMETER T = ACTUAL TEMPERATURE T_a = AMPLITUDE OF CHANGE IN T τ = CHARACTERISTIC TIME OF THERMOMETER	t = TIME AFTER BEGINNING OF CHANGE T_f = PERIOD OF FORCING FUNCTION = $2\pi/\omega_f$ $\mu = \frac{1}{\sqrt{1+\omega_f^2\tau^2}}$	$\phi = \tan^{-1}\omega_f\tau$	μ & ϕ ARE PLOTTED IN ACCOMPANYING FIGURE AS FUNCTIONS OF $\omega_f\tau$	

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Chart III

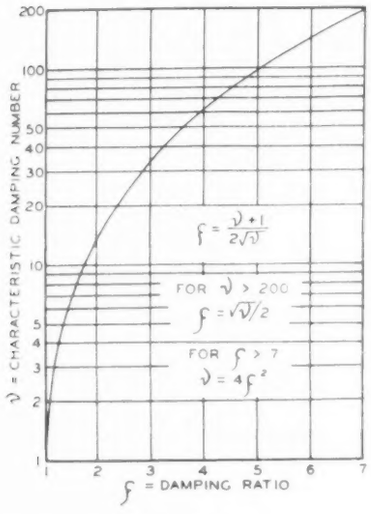

Fig. 4. Characteristic damping number as a function of damping ratio.

by the relationship

$$\omega_n = (2\pi)/T\sqrt{(1-\zeta^2)} \qquad (18)$$

For cases in which more than critical damping exists, the *characteristic damping number* ν can be found by the method given on Chart I. The corresponding value of the damping ratio can be conveniently read from the curve of Fig. 4.

When a step function is applied to a thermometer which obeys Eq. (15) the transient is a simple exponential of the form

$$(T_0 - T_1)/(T_0 - T_1) = e^{-t/\tau} \qquad (19)$$

where

T_0 = temperature of the primary element before the sudden change takes place in fluid temperature

T_1 = temperature of the fluid after the sudden change in fluid temperature.

From Eq. (19) it follows that the chacteristic time τ is the time interval required for the primary-element temperature to complete 63% (1—1/e) of the change from T_0 to T_1. Similarly, 86% and 95% of the total change will be completed in 2τ and 3τ respectively.

Steady State Response

The form of the equation which expresses the steady-state behavior of an elementary instrument depends not only on the instrument itself but also on the form of the forcing function. This fact makes it necessary to treat each forcing function as a special case. Certain forcing functions can be applied to such a wide range of problems that a branch of engineering has been developed about the corresponding steady-state solutions. An illustration of this statement is the sinusoidal forcing function which is so useful in the fields of alternating currents and vibrations.

Steady-state solutions are most conveniently found with the fundamental differential equation written in terms of scale readings as the dependent variable. The steps required to reach this form have already been reviewed for the case of the engine indicator. The equation to be solved becomes

$$d^2q_s/dt^2 + (2\zeta\omega_n)\,dq_s/dt + \omega_n^2 q_s = \omega_n^2 q \qquad (20)$$

It is apparent that the thermometer equation is a special case of Eq. (20) in which the second derivative term is not present and the coefficient of the first derivative term has been made unity so that

$$dq_s/dt + q_s/\tau = q/\tau \qquad (21)$$

In these equations a mathematical form is used for q which most nearly expresses the way in which the measured magnitude varies with time. It follows that q represents the scale reading if no dynamic error is present while q_s is the scale reading which actually occurs in response to changes in q.

After a suitable mathematical forcing function has been found to fit the physical changes in the measured magnitude the first step is to find an expression which satisfies the differential Eq. (20) or (21). This expression will serve as the steady-state solution corresponding to the given forcing function.

Forcing functions of five types which are often useful in engineering problems are shown in Charts II and III. Chart II shows the behavior of an elementary instrument which satisfies Eq. (20). Chart III shows the behavior of a thermometer which satisfies Eq. (21). In Chart II the forcing functions are indicated by heavy lines on plots in which time is taken as the abscissae and the ordinates are ratios between the scale reading q_s (or in the case of the forcing function, the true value of the measured magnitude) and some convenient value of the measured magnitude. The corresponding steady-state solutions are given as the first part of the expression on the right hand side of each of the response equations which are tabulated below the forcing function plots.

The steady-state solutions for the step function and the case in which the measured magnitude increases linearly

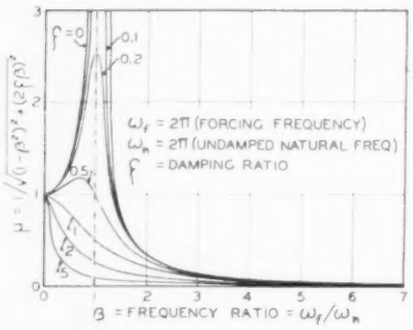

Fig. 5. Amplitude ratio as a function of frequency ratio for various values of damping ratio.—Sinusoidal forcing function.

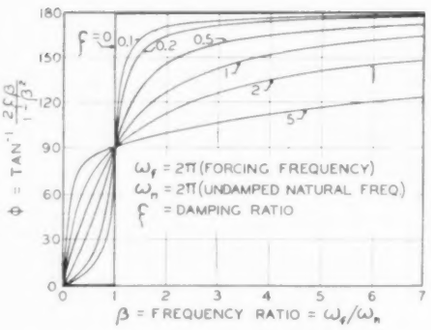

Fig. 6. Phase angle as a function of frequency ratio for various values of damping ratio.—Sinusoidal forcing function.

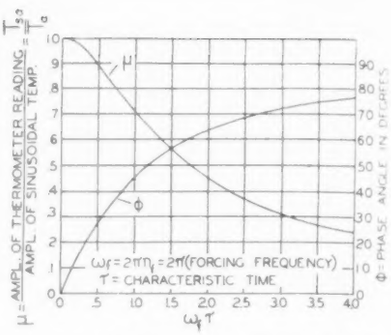

Fig. 7. Amplitude ratio and phase angle curves for a thermometer.—Sinusoidal forcing function.

with time involve only constants and simple algebraic expressions. For the cases in which a less abrupt change than that of the step function is approximated by means of a quarter-period or a half-period of a sine wave, a somewhat complicated expression μ and a *phase angle* ϕ are required. These same functions appear in the steady-state solution for a continuous sinusoidal oscillation of the measured magnitude. Both μ and ϕ depend upon the damping ratio ζ, the undamped natural circular frequency ω_n and the period of the sine wave used in the forcing function. To facilitate work with forcing functions of this type, values of μ for various values of the damping ratio are plotted against the *frequency ratio* as abscissae in Fig. 5. Corresponding plots for the phase angle ϕ are given in Fig. 6. The frequency ratio β which appears in Figs 5 and 6 is always the ratio between the frequency corresponding to a complete cycle of the forcing function and the undamped natural frequency of the system which responds to this forcing function.

It will be noted that the curves of Fig. 5 are identical with the resonance curves which appear in studies of mechanical vibration.[8] Further information on the treatment of problems involving sinusoidal forcing functions can be found in any text on vibration theory.

Chart III presents a similar treatment of a thermometer. Since the characteristic time is the only quantity in the thermometer equation which depends upon the instrument itself, there can be only one response curve for any particular forcing function. In the case of a forcing function having a definite frequency, the steady-state response can be found by methods similar to those developed in vibration studies. This means that the steady-state response of a thermometer to sinusoidal temperature changes can be specified in terms of two curves as shown in Fig. 7. In each case the independent variable is $\omega_f\tau$ which is 2π times the ratio of the characteristic time to the period of the forcing function. For one curve the ordinates are the ratio of the amplitude of the thermometer reading to the amplitude of the forcing function. The other curve is a plot of phase angle against the independent variable defined above.

Complete Response Equation

The way in which an elementary instrument responds to a change in the measured magnitude depends not only upon the characteristics of the particular instrument and the nature of the forcing function but also upon the reading and the rate of change of the reading at the instant when the forcing function is applied. Mathematically this means that the *fitting constants* A, B . . . which appear in the general transient equations given in Chart I must be so chosen that the expression for the reading in terms of time will fit the *initial conditions*.

It is obviously impossible to list all the possible combinations of forcing functions and initial conditions, so individual problems will always require particular solutions. However, the special case in which the elementary instrument has a constant reading equal to the true value of the measured magnitude at the initial instant can be applied to many practical problems. This set of conditions often occurs in connection with studies of automatic control where it is desired to indicate immediately any change which may occur in the controlled variable.

The equations tabulated in Chart II for oscillatory and non-oscillatory systems are based on the assumption that the reading has a constant value of zero with the measured magnitude equal to zero at the initial instant. It is obviously possible to apply these results to deviations from a constant value of the measured magnitude not equal to zero if the instrument is adjusted to read zero at this constant value. As an illustration of the information which can be obtained from these equations, three response curves are plotted for each of the five forcing functions. The undamped natural frequency of the elementary instrument was assumed to be the same for all cases. Damping ratio values of 0.2 and 1 were used for two of the curves while a characteristic damping number of 10 was used for the third curve of each plot. The group of curves thus represents the effect of changes in the damping on the response of an elementary instrument to various forcing functions.

The complete response of a thermometer to a change in temperature depends on the characteristics of the particular thermometer, on the nature of the forcing function and on the reading at the instant when the forcing function is applied. The rate of change of reading is not required as an initial condition for this case. The equations tabulated in Chart III are based on the initial conditions of a scale reading equal to the actual temperature at the value "zero." As in the case of the elementary instrument, *any* scale reading can be taken as the reference level for temperature changes.

Conclusion

The foregoing discussion is not new in the sense that novel methods or previously-unknown theoretical conclusions are presented. On the other hand, it does bring certain useful mathematical tools together in a systematic manner and outlines a scheme whereby these results can be put to work on practical problems by engineers who have neither the inclination nor the time to carry out all the details for themselves. The methods suggested and the system of nomenclature outlined are especially valuable when it is desired to determine the performance of elementary instruments as primary elements in automatic-control systems. It is hoped that studies of automatic control which are now in progress will produce generalized results along the lines discussed above for elementary instruments.

The general system outlined above has been found to work well in a variety of practical cases.

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A Method of Integrating Concentric Ring Areas

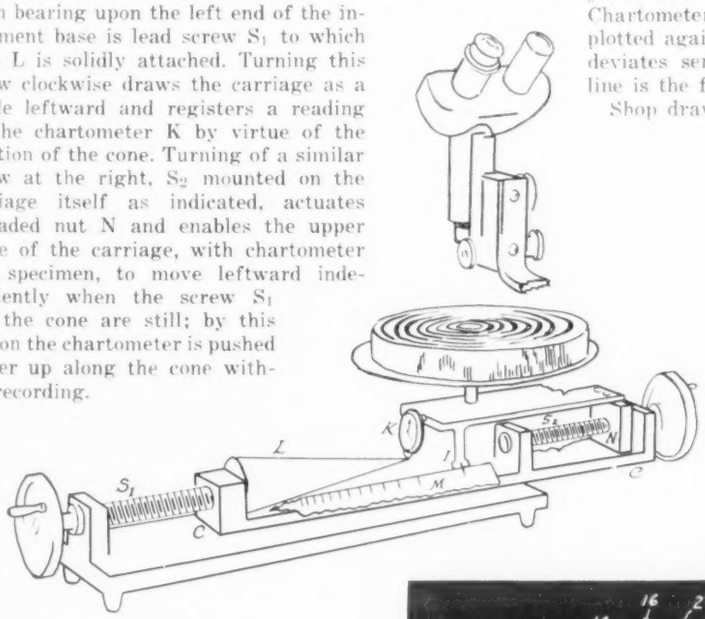
By E. R. SCHAFER and J. C. PEW

U. S. Forest Products Laboratory, Madison, Wis.

DETERMINATION of circular areas by the length of a spiral described about a right circular cone is the principle of measurement used in the Circometer*, an instrument recently developed by the writers as an aid in wood evaluation studies. This integrating cone principle (not known to have been used previously for the purpose here described) is applicable to any case requiring numerous measurements of separate concentric band areas, with or without summation.

The need was for a quick method of finding the actual and relative content of light, soft springwood and denser summerwood in given wood specimens, as an index to their pulping qualities. In the common case of disk sections sawed from the tree trunk, in which springwood and summerwood appear as alternate rings, target fashion, the task of scale measurement and computation of each light or dark ring as a separate product of width by radius by 2π is particularly tedious and subject to crude errors. By use of the circometer the area of summerwood rings can be rapidly and accurately integrated and the springwood area found by subtraction from the area of the whole disk, or vice versa.

The instrument makes use of a chartometer—a standard device actuated by a tracing wheel for linear measurements—which is caused to mount upward along an element of the horizontal cone as the wood disk is moved laterally under a scanning microscope. Its working can be understood from the adjoining diagram. Scanning begins by setting the center of specimen under the stationary microscope; travel of the carriage CC with specimen and chartometer K is from right to left. The chartometer is free to move upward in a vertical guide, not shown; the plane of its wheel is transverse to the cone element. Mounted in a plain bearing upon the left end of the instrument base is lead screw S_1 to which cone L is solidly attached. Turning this screw clockwise draws the carriage as a whole leftward and registers a reading on the chartometer K by virtue of the rotation of the cone. Turning of a similar screw at the right, S_2 mounted on the carriage itself as indicated, actuates threaded nut N and enables the upper stage of the carriage, with chartometer and specimen, to move leftward independently when the screw S_1 and the cone are still; by this motion the chartometer is pushed higher up along the cone without recording.



In use, screws S_1 and S_2 are turned alternately; S_1 for shifting bands of one kind (say summerwood) past the crosshair of the microscope, S_2 for shifting bands of the other kind. Thus the chartometer accumulates increments for the summerwood component alone, while the total movement of the disk along its radial line is registered by index I on scale M, fixed to the instrument base in front.

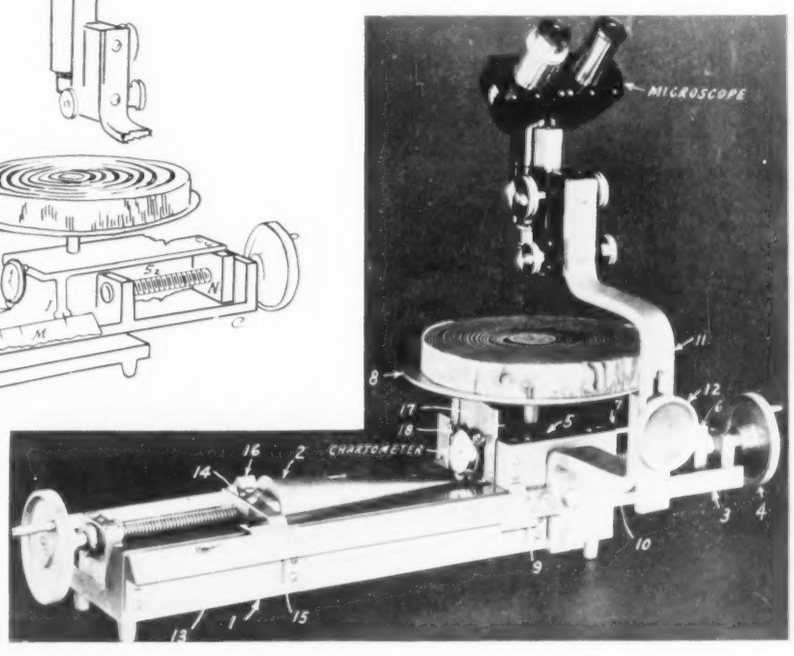
Scale M is graduated in square inches of circular area, corresponding to the second power of the length of radius traversed. The chartometer readings likewise correspond to the areas, not merely the widths, of the several summerwood areas traversed. Thus, by multiplying the chartometer reading by an instrumental constant (0.67 in the present model), and dividing the result by the reading of the scale M, the proportion of summerwood to the whole area (and hence volume) of the specimen is at once determined.

The above conclusion is based on the assumption of perfectly circular rings in the tree section. Since this is never exactly the case, traverses are taken usually along four radii at right angles to one another, and the readings averaged. In the case of exceptionally uniform specimens, traverses of two radii at 180° are found sufficient. The work of manual and visual operation is in all cases easy and rapid. Obviously, the chartometer can be used to accumulate either summerwood or springwood areas as preferred.

Measuring increments of area by the chartometer, an essentially linear measuring device, need offer no logical difficulty when it is considered that the wheel, while measuring, executes about the cone a virtual path of rotation whose length, in the first place, corresponds to a certain amount of rotation of screw S_1, *i.e.*, the *thickness* of the ring that is being measured; in the second place, the length of its path increases with its increasing height above the axis of the cone, which in turn is proportional to the distance of the wood ring from the center of the piece, *i.e.*, the *radius* of the ring. These two factors jointly—thickness times radius of ring—produce a reading which, within mathematical limits, is proportional to the *area* of the ring, wherever occurring in the specimen.

Such an explanation is in practical agreement with a stricter analysis of the wheel's path considered as a projected Archimedean spiral generated about a space axis. Chartometer readings taken for known circular areas and plotted against them give a calibration graph that nowhere deviates sensibly from a straight line. The slope of this line is the factor 0.67 mentioned above.

Shop drawings of the instrument are available.



*from the Greek word *kirkos*, meaning a ring.

Model Experiments on Tillage Tools

By KALMAN J. DE JUHASZ and A. W. CLYDE

Associate Professor of Engineering Research — Agricultural Engineer

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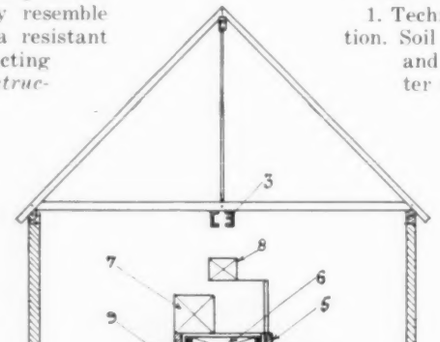
TESTING small scale models of structures and devices instead of the full-size prototype is a well-developed method used extensively in several branches of engineering. A few examples are: *aerodynamics*—airships, airfoils, fuselages, propellers, automobiles, and locomotives; *hydraulics*—ship hulls, seaplane floats, ship propellers, turbines, centrifugal pumps, conduits, river beds and ocean beaches; *structural engineering*—bridges, buildings, cranes, dams, gas reservoirs, etc.

Many modern laboratories in these fields conduct model experiments. Without them, today's high-speed vehicles and large structures would hardly have been possible.

The problems of soil tillage closely resemble those of other machinery moving in a resistant medium. The knowledge of soil forces acting on a tillage tool is of value for its *construction* (dimensions for strength and suitable shape) and its *operation* (method of hitching and determination of optimum speed). Tillage tools have been designed and operated mainly by trial-and-error methods, supplemented recently to some extent by scientific quantitative measurements on tools in operation at the Technischen Hochschule, Munich, the Federal Tillage Laboratory, Auburn, Alabama, and the Pennsylvania State College. Aside from some work with the motion of soil on plows, and with tractor lugs, no systematic model experiments are known to have been made in this field, though it is likely that much needed knowledge could be secured by this convenient method.

The following tentative outline is given for the proposed construction of a "model testing trough" for study of tillage tools.



1—Trough; 1a—Rail; 2—Trap door; 3—Overhead rail; 4—Dump truck; 5—Reference frame; 5a—Skid; 6—Sub-frame; 7—Recorder; 8—Camera; 9—Observer's seat; 10—Tillage tool.

The Model Testing Trough. A trough, 40 to 50 feet long, 3 to 4 feet wide and about 12″ deep, is filled with soil, the characteristics of which can be varied according to the needs of the test. Its bottom, located about 18″ above floor level, is provided with trap doors. Above the trough runs an overhead tramrail or trolley and below it a narrow-gage railway, to expedite changing soils. The soil is mixed to the required specification as to composition and moisture content and is leveled and compacted in place to the desired consistency and hardness. The upper edges of the trough are finished to a straight level surface to serve as a runway for the carriage.

The Carriage consists of two parts: the reference frame and the subframe.

The reference frame, mounted on wheels or skids, may be easily moved on, but is accurately guided by the runway. An electric motor and a suitable rope-drum, or a hydraulic cylinder and system of pulleys, can be used to propel the carriage. The speed can be varied or kept constant, and measured accurately. On this reference frame are mounted (1) instruments for recording the speed, distance traveled, time, forces, and other data; (2) a motion-picture camera for filming the motion of the soil under the action of the tillage tool; (3) the observer's seat.

The subframe, to which the tool is attached, is connected to the reference frame at three points in such manner as to allow a small amount of relative displacement with six degrees of freedom. The displacements are resisted by elastically yielding elements whereby the forces can be measured and recorded by suitable instruments. The six components of the forces acting on the tillage tool are thus determined as is being done with boat hulls, airplanes, full-size tillage tools, etc. Mechanical features and instrumentation appear to offer few difficulties because there is much experience along these lines. It may be added that optical and electrical methods of indicating and recording are useful when a high degree of sensitivity is required.

There are, however, two features connected with the soil which would need careful study. They are:

1. Technique of obtaining the desired soil condition. Soil is not a homogeneous material like air and water. The stability of the colloidal matter changes with age; it might prove desirable to allow soil to "age in the trough." Some sort of vibrator might be better than a tamper for compacting. So far, penetrometers have not given satisfactory correlation with the resistance encountered by tillage tools. They probably are influenced too much by the compressibility of the soil. Some other device which will be affected more by shearing may prove to be better.

2. Relating results to field work. The size of soil particles will not be reduced in the same degree as the model tool is reduced; it is quite likely, therefore, that a scale effect (forces not reduced in direct proportion to the size of the tool) will exist as is found with other media; and it will be necessary to work out this relationship. Perhaps laboratory soil conditions can be found which will correspond to (but not necessarily be equal to) certain field conditions.

Some of the Data Obtainable from this Type of Equipment: (1) Soil reaction on tools; (2) Variation of reaction with speed, depth of cut, composition and condition of soil, orientation of the tillage tool; (3) Optimum arrangement of hitching; (4) Constructional data for implement design, such as size and shape of parts, bearing loads, etc.; (5) Degree of tillage produced by different tools and various settings of each.

Tests with such an equipment are free from limitations of weather, time of day and season. Tests can be made under controlled conditions, closely simulating those for which the tool is intended. Numerous tests can be made in a relatively short time without inconvenience and danger. The cost of making a small model is much less than that of a full-size tool, and a variety of constructions can be tried out for finding the best design. Observing the tool in actual operation, in comfort, being able to give attention to all its features, action and behavior, is a powerful aid to imagination when a fault has to be eliminated, or the design improved. Such model tests are also a valuable aid in engineering education, and in illustrating novel developments before professional groups.

Thought is being given at The Pennsylvania State College to the possibility of such method of testing as a supplement to the work with full-size tools in the field. It is expected that such a model-test equipment, when built, will usefully serve the advancement of agricultural engineering.

Continued from page 127

[illegible] and rehashes it in even yellower style. No reliable lie-detecting instrument has ever been built; no reliable principle of instrumental lie detection has ever been discovered.

Pages 234-242 on radio aids to aircraft navigation will edify Dr. Brombacher and the N.A.C.A., particularly where Yates explains that the "actuating impulse or signal is radiated by a short-wave receiver" or where he explains "what is now known as the Kennelly-Heaviside layer" or reports a "new" German system as the first and only solution of the blind-landing problem, ignoring three previous American systems which probably are better.

With such knowledge of what he is writing about, Yates feels himself qualified to make predictions. And does! They sound screwy to this reviewer but Yates cites various well-known historical examples of skeptics who said it couldn't be done, so perhaps astrology *will* become an exact science; perhaps the "sound-conditioned house of the future" *will* be in a zone of silence created not by tangible insulation but by a "counter-acoustic barrage" as Yates explains:

"there is no reason why two sound waves of the same intensity and wave-length could not be made to collide with each other in such a way as to bring about mutual annihilation or silence." The "counter-acoustic barrage . . . rushes forth to meet and slay the noisy intruders" but what this reviewer wants to know is how are we to be protected from the "counter-acoustic barrage"?

Perhaps "short waves" *will* heat our bodies in winter so that we shall be "able to go through domestic routine even on sub-zero days covered by the minimum needed to flag a handcar or stuff a knothole" but how will our skins be kept warm?

Perhaps etched-metal phonograph records *will* be sold at "ten cents the copy" of a novel or of a complete opera, but what wages will be paid to the workers on the complicated processes described (or hinted at) by the author?

Perhaps "the printing industry lies in great danger. . . . Television . . ." but we stockholders in publishing firms aren't going to let Yates scare us into dumping our holdings!

Perhaps the "photo ear-book' *will* "change our reading habits" so that the tired businessman will "lounge in his easy chair after dinner and drink in through his ears and with his eyes closed the contents of *Time, Cosmopolitan* or *Harper's*" but what about the t.b.m. who today refuses to burden his mind with entire news broadcasts because he only wants certain topics?

Perhaps we *shall* see "the dawn of that day when reading even by the aid of the ear-book will be outmoded by the appearance of the robot who [*sic*] will whisper our news, our love stories and essays to us while we sleep. . . . Given a method of appealing to it [the subconscious] directly, we shall have a means almost of making intellectual giants out of drooling imbeciles. . . . Some form of undiscovered electromagnetic radiation . . . will carry a supersensible [*sic*] appeal directly to the seat of intelligence without so much as disturbing our sleep." Whoever doubts this is called by Yates a "stupid skeptic."

Well, this reviewer doubts that any form of electromagnetic radiation can make an intellectual giant out of an imbecile, and is old-fashioned enough to believe that the brain is like a muscle: to improve it you've got to exercise it. This fantasy of conditioning human beings while they sleep was cleverly put forth by Aldous Huxley in "Brave New World." The reviewer and some of his *adult* friends enjoyed it as a delicious bit of satire; we never imagined that a professional writer smart enough to find a publisher would swallow it literally, embroider it with undiscovered-electromagnetic-radiation twaddle and call doubters "stupid skeptics."

On page 124 Yates uses the term "pseudo-science." We can't imagine a more exact description of his book as a whole. On page 125 he refers to "lurid predictions from the Sunday feature writers." We believe this to be an apt characterization of his own predictions. But enough of this latest anti-machine diatribe. We picked it to pieces because it might prove to be the most destructive if its teeth aren't pulled. The World of To-morrow will be seriously retarded if you and we don't do our utmost to neutralize every new injection of ideological poison shot into the body politic by crackpot writers and fanatical radio preachers. By the same token, let's throw our full support behind every new book or pamphlet designed to aid scientific and technological progress. Last month we mentioned the A.S.T.E. Fact Finding Committee's Report. Since then there has appeared

Machinery and the American Standard of Living. (Pamphlet No. 8). Machinery and Allied Products Institute, 221 North LaSalle St., Chicago, 1939. Paper, 5½ × 8½ inches, 88 pages. Free.

which, though free, is as workmanlike a book as any economic text selling for several dollars. We don't boost it blindly: we read it and found it less than perfect (page 83 is weak precisely where David Cushman Coyle has made a strong argument in differentiating between "business" and "finance"—see *Instruments*, March 1934, page 41—and this doesn't mean that we agree all the way with Coyle) but we unhesitatingly recommend this pamphlet as the richest in irrefutable demonstrations of technology's con-

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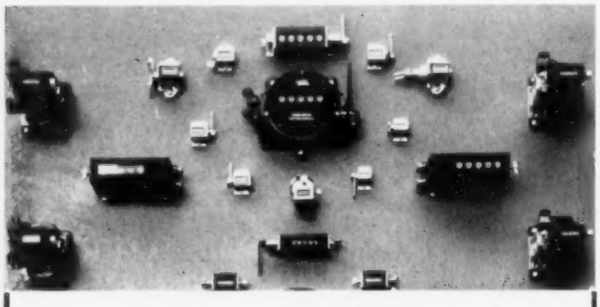
In one of the World's Fair exhibits (or elsewhere, in the last few days) we came across the excellent slogan: "Today's Research Creates the World of To-morrow." To which there is an obvious sub-slogan: "The more efficient the research, the more it hastens To-morrow and the better To-morrow it creates." The most efficient research, of course, is that which is free from what Dr. McDonald, Director of the Biochemical Research Foundation of the Franklin Institute, called THAT CRIME AGAINST RESEARCH—DUPLICATION. In this connection it is not an idle boast to declare that (as you've heard) instruments are the tools of Research and that (as you should bear in mind) *Instruments* is the essential tool of every type of modern research laboratory because it is the greatest little crime-preventer that research men can use. On that flying visit to New York from which we've just returned, we dropped in on Professor Müller whose laboratories at New York University are model homes of efficient research. He and his associates never commit the crime of duplication because he has been an *Instruments* subscriber from the start and because they always use not only their complete files of *Instruments* but the Information Service of The Instruments Publishing Company. He told us some amusing (and pathetic) stories of other research groups designing and building "Rube Goldbergs" although components and even complete assemblies were available on the market, thereby committing Crimes Against Research, because these unfortunates weren't subscribers to *Instruments*. We may sound commercial, but we really mean to promote efficient research and help create the World of To-morrow, in urging you, fortunate subscriber, to bring this important matter of "crime-prevention" to every research man you know.—MFB



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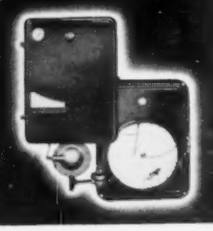

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